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Will Unconventional, Horizontal, Hydraulic Fracturing for Shale Gas Production Purposes Create Environmental Harm in the United Kingdom?

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Lincoln Law School, College of Social Science

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Abstract

In April 2018 Cuadrilla Resources successfully drilled the UK's first horizontal shale gas well in Lancashire. Whilst there is an abundance of academic research on the environmental impacts of fracking (primarily in North America), there is no scholarship that specifically considers what environmental harms may occur from fracking in a UK context. This thesis is therefore an important, original contribution to academic understanding and is presented at a vital time in the development of fracking in the UK where production of shale gas is imminent.

In order to assess the potential for environmental harm, 20 semi-structured interviews were conducted with a variety of key-informants (people possessing important expertise of one or more areas of the fracking process in the UK). These key-informants came from a variety of backgrounds and included: 5 Anti-Fracking Campaigners; 3 Academics; 3 Employees from Regulatory Bodies; 2 Geological Consultants; 1 Journalist; 1 Parish Councillor; 1 District Councillor; 1 Water Consultant; 1 Oil and Gas Professional; 1 Oil and Gas Consultant; and 1 Gas Company Director. Interview questions were derived from a literature review that revealed different opportunities for environmental harm to occur based on a variety of academic and organisational research. As a result, interview questions centred on water (specifically; water aquifers, water resources, and wastewater) and other aspects (seismicity, chemical usage, well integrity and flaring).

Treadmill of Production and eco-philosophy were used as theoretical underpinnings of the research. Treadmill of Production provides an understanding of why fracking has emerged in the UK, concluding that the demise of North Sea oil and gas is leading to the increased attractiveness of more extreme energy sources in order to keep the treadmill running. The harms identified in the results chapters are forms of ecological withdraws and additions that lead to ecological

disorganisation. Additionally, eco-philosophy provides three different perspectives from which to view human interactions with shale gas resources. The conclusion is that fracking clearly represents an anthropocentric approach to the creation of energy where human wants and needs are prioritised over the survival demands of humans, non-human species and the wider ecology.

The thesis is best situated within the discipline of green criminology due to the fact that fracking is a legal production process in the UK. It is suggested that green criminology is in a unique position to evaluate fracking, and that this is not possible in orthodox criminological discussions that view crimes solely as violations of criminal laws.

By conducting primary research prior to the development of fracking in the UK, this research has identified key areas for environmental harm to occur based on the expertise of a variety of key-informants. This is the first piece of research of its kind and it is argued that analysing the potential for environmental harm to occur prior to the production of shale gas is more beneficial that analysing environmental degradations after they have already occurred according to the precautionary principle of environmental law.

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Glossary

Term	Definition
Abandonment	‘To cease work on a well, which is non-productive, to plug off the well with cement plugs and salvage all recoverable equipment. Also, used in the context of field abandonment and commonly referred to as “decommissioning”’ (Oil and Gas Authority, 2017).
Biogenic Methane	Biogenic methane is ‘natural gas produced by living organisms or biological processes’ (Speight, 2013: 152) that exists naturally. This is different from thermogenic methane which is formed by anthropocentric processes (i.e. induced pressure) on organic matter.
Borehole	‘A generalized term for a shaft bored into the ground’ (Speight, 2013: 152).
Bowland Shale	The Bowland shale is an ‘Early Carboniferous organic-rich shale basin’ that underlies much of Northern England, particularly Lancashire and Yorkshire (Andrews, 2013: 18).
Carcinogen	A carcinogen is a substance that can cause cancer in humans and animals.
Coal-Bed Methane	Coal-Bed Methane is ‘natural gas extracted from coal beds. It is usually produced by drilling a borehole into a coal seam, reducing the pressure of water flowing through the seam, and allowing the gas held to flow up the borehole to the surface’ (Prud’homme, 2014: 22).

Conventional Hydraulic Fracturing	Conventional hydraulic fracturing is a traditional hydrocarbon extraction technique that involves only vertical drilling of a borehole in order to extract oil and gas contained within conventional, highly permeable geological formations (such as sandstone and limestone).
Conventional Hydrocarbons	‘Oil or gas extracted from high-permeability rocks, usually from single discrete geological structures’ (Stephenson, 2015: 147).
Dirty Gas	This is the first gas that flows into the wellbore and constitutes many different substances including natural gases, fluids used to drill or fracture the well, and other sub-surface geological matter that is present at that time.
Fault Line/s	‘A crack or fracture in the earth along which movement can occur or has occurred’ (Stephenson, 2015: 147).
Fissure	A fissure is ‘an extensive crack, break, or fracture in the rocks’ (Pattison Sand Company, 2016).
Flaring	Flaring is ‘the burning of unwanted gas through a pipe (also called a flare). Flaring is a means of disposal used when there is no way to transport the gas to market and the operator cannot use the gas for another purpose’ (Schlumberger, no date).
Flow-Back Water	Flow-back water can be defined as ‘the fluids that return to the surface after the step of hydraulic fracturing and before oil and gas production begins, primarily during the days to weeks of well completion’ (Jackson et al. 2014: 342). Flow-back water generally

	consists of 10-40% fluids and chemicals used in the process and the rest comprises natural brines originating from within the earth's geology (Jackson et al. 2014: 342).
Fracking Fluid (also known as: Fracfluid or Fracturing Fluid)	Fracturing fluid is defined by Schlumberger (no date) as 'a fluid injected into a well as part of a stimulation operation. Fracturing fluids for shale reservoirs usually contain water, proppant, and a small amount of nonaqueous fluids designed to reduce friction pressure while pumping the fluid into the wellbore. These fluids typically include gels, friction reducers, cross linkers, breakers and surfactants similar to household cosmetics and cleaning products; these additives are selected for their capability to improve the results of the stimulation operation and the productivity of the well.'
Fractures	A fracture is 'a crack or surface of breakage within rock not related to foliation or cleavage in metamorphic rock… Fractures can enhance permeability of rocks greatly by connecting pores together, and for that reason, fractures are induced mechanically in some reservoirs in order to boost hydrocarbon flow' (Schlumberger, no date).
Geologic Pressure	Geologic pressure (also known as geo-pressure) is defined by Schlumberger (no date) as: 'the pressure within the earth, or formation pressure. The common oilfield usage, however, is to indicate anomalous subsurface pore pressure that is higher or lower than the normal,

	predicted hydrostatic pressure for a given depth.'
Groundwater	'Water naturally distributed in rocks underground' (Stephenson, 2015: 147).
Horizontal Well	According to the International Association of Drilling Contractors (2013) a horizontal well is 'a well which is drilled in such a way that the wellbore deviates laterally to an approximate horizontal orientation within the target formation with the length of the horizontal component of the wellbore extending at least one hundred feet in the target formation, measured from the initial point of penetration into the target formation.'
Hydrocarbon	'An organic compound containing only carbon and hydrogen. Hydrocarbons often occur in petroleum products, natural gas and coals' (Speight, 2013: 156).
Impermeable	Permeability is the ability for liquid and gas to flow through matter, in this case, through rock (particularly shale rock). Therefore, a material with high–permeability allows liquids and gases to flow through easily (such as in limestone and sandstone formations). Correspondingly, a material with low-permeability does not allow liquids and gases to flow through easily (such as shale formations). Therefore, shale is impermeable, whereas sandstone and limestone are permeable.
Impure Natural Gas	'Natural gas as delivered from the well and before processing (refining)' (Speight, 2013: 156).

Methane	'A fossil fuel with the formula CH4, which is the most common component of natural gas' (Stephenson, 2015: 147). Other components depend on the source, but can include 'propane, butane, hexane and benzene' (Eapi, et al. 2014: 928).
Migration	Migration in this thesis means the ability for substances (i.e. fracfluids) to migrate vertically upwards via fractures, fissures or geological fault lines. It also refers to the ability of substances (i.e. fracfluids) to migrate out of well casing into the surrounding area (i.e. via total well failure).
Multiple Barrier System (MBS)	'Multiple barriers are nested individual barriers designed and built to withstand a specific load without help from other barriers. If an inside (or outside) barrier fails, the next barrier will provide isolation so that a leak path will not form' (King and King, 2013: 324).
Naturally Occurring Radioactive Material (NORM)	NORM is 'Naturally Occurring Radioactive Material (that) exist naturally in many different rock types. In shales, there are small amounts of radioactive materials such as Radium-226. When shales are fracked, small quantities of these can be brought to the surface' (ReFINE, no date).
Orphan Well	'In the upstream oil and gas industry, an orphan is a well, pipeline, facility or associated site which has been investigated and confirmed as not having any legally responsible and/or financially able party to deal with its abandonment and reclamation responsibilities' (Orphan Well Association, 2003).

Permeability	'The ability of a rock to allow fluids to flow through it' (Stephenson, 2015: 148).
Porous	Porosity can be defined as 'the amount of pore space or void between the constituent particles of a rock' (Stephenson, 2015: 148).
Produced Water	Produced water can be defined as 'the fluid that flows to the surface during extended oil and gas production' (Jackson et al. 2014: 342) the brines of which can be very saline (like saltwater).
Proppant	'Small particles, usually of sand, that are injected into new hydraulic fractures to keep them open' (Stephenson, 2015: 148).
Radon	'Radon is a naturally occurring radioactive gas created when uranium and radium in the soil and rocks decays' (Howard, 2012: 7).
Richter Scale	The Richter scale is a mathematical device developed in 1935 by Charles F. Richter at the California Institute of Technology. It is used to measure and compare the size of earthquakes (United States Geological Survey, no date).
Seismicity	Seismicity (or seismic events) refers to earthquakes. These can occur naturally as a result of tectonic movement and the movement of geologic faults. Induced seismicity 'is an earthquake caused by human activities' which can occur as a direct result of hydraulic fracturing, or through the re-injection of wastewater (Clark et al. 2012: iv).
Shale Formation	See; shale rock.
Shale Gas	'Natural gas stored in low-permeability shale formations' (Speight, 2013: 161).

Shale Reservoir	A reservoir is ‘a subsurface, porous, permeable rock body in which oil or gas or both have accumulated’ (United States Geological Survey, 2014). A shale reservoir, although impermeable, is therefore a rock body in which oil and/or gas has accumulated from organic matter (such as fossils) over millions of years.
Shale Rock	Shale is ‘a fine-grained, fissile, detrital sedimentary rock formed by consolidation of clay and silt sized particles into thin, relatively impermeable layers. It is the most abundant sedimentary rock’ (Schlumberger, no date).
Strata	‘Layers including the solid iron-rich inner core, molten outer core, mantle, and crust of the earth’ (Speight, 2013: 161).
Substances	Substances are both substances used in fracfluid and matter that is retrieved from deep geology in flow-back water (i.e. organic material and brines).
Surface Water	Surface water is water that is visible on the earth’s surface such as water in rivers, lakes, oceans and canals.
Target Locations	The location (within the shale formation) that an operator hydraulically fractures in order to retrieve hydrocarbons.
Thermogenic Methane	Thermogenic methane is ‘gas formed by pressure effects and temperature effects on organic debris’ (Speight, 2013: 161). This is different from biogenic methane which is gas (formed from organic matter) but has been released, or exists, naturally (i.e. has not been released anthropocentrically).

Tight Gas	'"Tight gas"' refers to natural gas produced from reservoir rocks of low permeability, such as shale or sandstone. Shale gas and other forms of tight gas are referred to as "unconventional" because of their atypical reservoirs, which require new production techniques' (Shonkoff et al. 2014: 787).
Upwards Vertical Migration	See; migration.
Unconventional Hydraulic Fracturing	Unconventional hydraulic fracturing is a hydrocarbon extraction technique that involves the (firstly vertical and then horizontal) drilling of a borehole in order to extract oil and gas contained with unconventional, low-permeability geological formations (such as shale).
Venting	Venting is gas that is 'freely released into the atmosphere' (Peduzzi and Harding Rohr Reis, 2013: 88). This is different from flaring, which is the burning of gas into the atmosphere.
Viscosity	'The measure of a fluid's thickness or how well it flows' (Speight, 2013: 162).
Volatile Organic Compounds (VOCs)	'Compounds regulated because they are precursors of ozone; carbon-containing gases and vapours from incomplete gasoline combustion and from the evaporation of solvents' (Speight, 2013: 162).
Unconventional Hydrocarbons	'Oil and gas extracted from low-permeability rocks' (Stephenson, 2015: 148).
Wastewater	Wastewater is generally classified into produced water and flow-back water (Jackson et al. 2014: 342). Please see their respective definitions.

Water Aquifer	'A rock formation that is sufficiently porous and permeable to yield a significant quantity of water to a borehole, well or spring. The aquifer may be unconfined beneath a standing water table, or confined by an impermeable or weakly permeable horizon' (British Geological Survey, 2017a).
Water-Bearing Rocks	Water-bearing rocks are 'types of rocks that can hold water, including sedimentary deposits (sand and gravel), channels in carbonate rocks (limestone), lava tubes or cooling fractures in igneous rocks, and fractures in hard rocks' (Groundwater Foundation, 2017).
Water Table	'The top of an unconfined aquifer; indicates the level below which soil and rock are saturated with water. The top of the saturation zone' (Groundwater Foundation, 2017).
Well Casing	'A series of metal tubes installed in the freshly drilled hole serving to strengthen the sides of the well hole, ensuring that no oil or natural gas seeps out of the well as it is brought to the surface, and keeping other fluids or gases from seeping into the formation through the well' (Speight, 2013: 162). The casing only prevents seepage if total well failure is avoided and well integrity is in-tact.
Well Decommissioning	See; abandonment.
Well Failure	The term well failure varies. For some, it means the complete failure of all well casings resulting in the leakage of liquids and gases

	into the surrounding environment. For others, it means the failure of a single (or multiple) casings which may not result in the leakage of liquids and gases. For more information on such terminology, please see: Davies et al. (2014: 239-240).
Well Integrity	Well integrity is ‘the ability of the well to prevent hydrocarbons or operational fluids leaking into the surrounding environment’ (Royal Society and Royal Academy of Engineering, 2012: 69).
Well Pad	‘The area around a shale gas well where machinery is positioned’ (Stephenson, 2015: 148).

List of Abbreviations

Abbreviation	Meaning
ARI	Advanced Resources International
BGS	British Geological Survey
Btu	British Thermal Units
CCS	Carbon Capture and Storage
CHD	Congenital Heart Defect
CO^2	Chemical Formula for Carbon Dioxide
DBEIS	Department for Business, Energy and Industrial Strategy
DCLG	Department of Communities and Local Government
DECC	Department of Energy and Climate Change
EA	Environment Agency
EPCRA	Emergency Planning and Community Right-to-Know Act
ESRC	Economic and Social Research Council
EU	European Union
ECHR	European Convention on Human Rights
The FRAC Act 2015	The United States Fracturing Responsibility and Awareness of Chemicals Act 2015
GHG	Greenhouse Gas
HCBP	House of Commons Briefing Paper
HSE	Health and Safety Executive
IA 2015	The Infrastructure Act 2015
LPA	Local Planning Authority
LNG	Liquefied Natural Gas
MBS	Multiple Barrier System
MWD	Mining Waste Directive
MSDS	Material Safety Data Sheets

NGD	Natural Gas Development
NTD	Neural Tube Defect
NGO	Non-Governmental Organisation
NORM	Naturally Occurring Radioactive Material
OGA	Oil and Gas Authority (UK)
PCF	Participant Consent Form
PEDL	Petroleum Exploration and Development Licence
RSRAE	Royal Society and Royal Academy of Engineering
SEPA	Scottish Environmental Protection Agency
SO^2	Chemical Formula for Sulphur Oxide
SoS	Secretary of State
SCP	Sustained Casing Pressure
tcf	Trillion Cubic Feet
TDS	Total Dissolved Solids
TLM	Traffic-Light Monitoring (System)
ToP	Treadmill of Production
UHF	Unconventional Hydraulic Fracturing
UK	United Kingdom
UKOOG	United Kingdom Onshore Operators Group
US	United States
VOC	Volatile Organic Compound
WEEE	Waste of Electrical and Electronic Equipment

Word Count of thesis (pages 27 - 307 only. This excludes the appendices, reference list, and everything that comes before this point): **79,879**.

Chapter One: Introduction

1.1. Background to the Research Topic and Subsequent Rationale

At the time of submission, there is no research that has documented environmental harm as a direct result of unconventional hydraulic fracturing (UHF) in the United Kingdom (UK) simply because the onshore UHF industry is currently in the exploration phase of development[1] and the technology has not yet taken off on a commercial scale[2]. Despite this, several companies have applications pending for both exploratory wells and the conversion of exploratory wells into production wells (Oil and Gas Authority (OGA), 2015).

Hydraulically fracturing shale rock in an unconventional manner to produce consumable natural gas has the potential to facilitate economic growth (Ochieng et al. 2015) in the UK through the creation of jobs and heightened energy security (Institute of Directors, 2013: 17). At the same time, slowly replacing coal with gas and decreasing the need to import liquified natural gas (LNG) could help the UK move towards a 'low carbon future' (Institute of Directors, 2013: 46). However, research from the United States (US) (Colorado Department of Public Health and Environment, 2008; Howarth et al. 2011a; Howarth et al. 2011b; Osborn et al. 2011), Canada (Becklumb et al. 2015; Council of Canadian Academies, 2014; Krzyzanowski, 2012; Rehu and Morgan, 2012) and Australia (Doctors for the Environment Australia, 2013; Redmond, 2014),

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[1] For a visual representation of the different stages of development expected for UHF in the UK, see Appendix One.
[2] There is some research from one well that underwent UHF in 2011 at Preese Hall in Lancashire (see, for example, Green et al. 2012). However, this operation resulted in a temporary moratorium on fracking in the UK and Parliament has since passed the *Infrastructure Act 2015* (Part 6 of which directly relates to UHF). Since this Act, however, at the time of submission, no UHF has occurred.

where shale gas production is at an advanced stage (when compared with the UK), highlights that natural gas extraction through the technique of UHF in these countries is associated with high levels of victimisation through the mediums of environmental harm, social harm and negative human health effects.

As a result, there are clearly conflicting political, economic and cultural interests where shale gas development is concerned. One side of the fracking debate wishes to utilise the technology for political and economic interests (this often includes: those involved in the fracking industry and supply chain; and government personnel backing fracking) whereas the other side wishes to prevent fracking in the UK (which often includes: anti-fracking campaigners; some political figures; and many local residents living in close proximity to fracking sites).

The primary aim of this research was therefore to gain knowledge, information and a deep understanding of the most salient economic and environmental issues surrounding fracking by conducting interviews with *key-informants* (those knowledgeable of some aspect of fracking, inclusive of both sides of the fracking debate). Doing this has aided in the ability to come to an informed conclusion as to the extent to which fracking may impact upon the environment, in the wake of government economic objectives and opposition from those who resist the establishment of a shale gas industry.

A further rationale for the thesis was to conduct research on the potential socio-environmental effects of fracking prior to the commencement of UHF on a commercial scale in the UK. Using this precautionary mind-set is undoubtedly far more beneficial for the environment (in terms of preventing environmental harm), than researching harm that has already occurred.

1.2. **Defining Fracking**

It is incredibly important to understand, at the outset, what is meant in the thesis by the various terms that are used. Within both academic literature and public discourse, several different names are used interchangeably which essentially refer to the same thing. Whilst the term *fracking* could refer to a multitude of different engineering processes, the specific form of onshore UHF that this thesis refers to, is also often encompassed under the broader notion of fracking. Chapter Two provides a great deal of detail with regards to the different engineering and geological components that together make the specific process under scrutiny in this thesis distinct from other similar processes that fall under the same umbrella term of fracking.

It is important, however, at this early stage to define exactly what is meant when certain terms are used interchangeably to represent the same process. As a result, the definition of *fracking* used in this research will refer to the following process:

> **Anthropocentrically induced multiple stimulation of an onshore well drilled in an unconventional fashion (vertically then horizontally) using high-volumes of fluid at high-pressures. This is specifically undertaken for the purposes of releasing gas trapped in deep, low-permeability, unconventional, geologic formations (shale only) in the UK.**

Due to the differing terminology used within academic research and public discourse, the following lexical phrases used within the thesis refer specifically to the definition of *fracking* cited above:

- Fracking
- Hydraulic fracturing
- Unconventional hydraulic fracturing

- Onshore unconventional hydraulic fracturing

Where the thesis uses other terminology, this refers to a different form of fracking separate from the definition provided in this section. For example, offshore fracking, or fracking for different types of hydrocarbon (coal-seam gas; shale oil; oil from other geological formations).

The thesis will also use terminology that is specific to the fields of study that are engaged by the research (geology; engineering; oil and gas). To enable the reader to fully understand what is meant by these terms, a glossary has been provided on pages 15-24 of the thesis. Additionally, a list of abbreviations for various terms can be found on pages 25-26.

1.3. **Situating the Research**

This thesis falls under the category of social science research and, more specifically, is situated within the discipline of criminology and (even more explicitly) the sub-discipline of green criminology. The rationale for this situation will now be outlined.

Environmental harms have largely been ignored by orthodox conceptions of criminological thinking because such harms are often the result of actions that do not violate the criminal law (Hall, 2012: 375; Stretesky et al. 2014; White, 2008). This does not mean however, that legal harms against the environment (such as those potentially created from the currently legal process of fracking) should not be treated as crimes when such harms cause significant damage to the environment or to human health. Some academics have realised this and, as a result, a new wave of *green criminology* is emerging within the wider criminological discipline that addresses the need to study environmental and social harms calling for more research to be conducted in the areas of green criminology and zemiology respectively (Brisman and South, 2014; Hall, 2015; Nurse, 2013; Stretesky et al. 2014; White, 2008; Wyatt, 2013).

This thesis will fall under this new wave of green criminology by examining the potential for environmental harm to occur from UHF processes in the UK. Accordingly, the literature review in Chapter Three will interact with green criminology literature, which encompasses Treadmill of Production theory (ToP) (Gould et al. 2008; Schnaiberg, 1980; Stretesky et al. 2014) and Eco-philosophy (Halsey and White, 1998; White, 2008). Interacting with this literature will provide a unique thesis examining a fossil fuel extraction technique that is an entirely new phenomenon in the UK which will make the thesis an original contribution to academic understanding.

1.4. **The Research Question**

The initial aim of the thesis was to identify if any processes associated with UHF in the UK may create environmental harm in contrast with any economic considerations. Being a complex engineering process, I decided that in order to more competently understand UHF (which would be necessary to conduct in-depth interviews with people who have a high-degree of knowledge with one or more aspects of UHF) it would be essential to conduct a detailed literature review prior to data collection. The aim (that did subsequently unfold) was to identify a series of questions based on the literature review to ask interviewees, a clear deductive approach to the research. Whilst previous academic enquiry brought up several environmental and economic issues regarding the process of UHF, these were limited largely to overseas research in jurisdictions that permitted UHF. As the UK was not producing gas from UHF for the entirety of the research, the questions posed to participants consisted of issues identified overseas. Therefore, asking interviewees questions based on these issues in a UK context has created an original piece of research that has not been done before.

It is recognised that applying overseas research to UHF in the UK is problematic in a number of ways. Firstly, the geology of different countries means that dissimilar UHF techniques are used in such locations in order to extract gas. Additionally, nations implement distinctive laws and regulations where oil and gas developments are concerned, which can lead to different processes being adopted. Furthermore, different companies using diverse machinery conducting their operations in distinctive ways lead to variable results. However, the processes that are proposed to be used in the UK (unconventional hydraulic fracturing as described in the definition provided in section 1.2.) are anticipated to be the same processes that are used in UHF processes overseas. In other words, the overall goal is the same which is to produce consumable supplies of gas using unconventional drilling techniques (horizontal drilling) in an unconventional geological formation (shale), using high-pressures and high-volumes of fluids to achieve that goal. Therefore, although the process may differ technically from place to place, the overarching objective is the same, and very similar (although not exact) techniques are deployed in the processes of achieving that goal.

Unfortunately, due to word count restrictions, the economic implications of UHF discussed with interviewees could not be included directly within the thesis[3] (although the literature review and interviews contributed to my understanding of the economic arguments surrounding UHF which has undoubtedly indirectly affected the research). During analysis of the interview data and collating results, it was decided that the word count would only allow examination of the environmental issues discussed in interviews and, as a result, the final, central research question for the research is as follows:

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[3] For more detail, see Chapter Four (Research Methodology).

What do key-informants understand to be the most salient concerns regarding the potential for unconventional hydraulic fracturing to cause environmental harm in the United Kingdom?

1.5. <u>**Overview of the Research Methodology**</u>

In order to identify key potentials for environmental harm resulting from UHF in the UK, I undertook a series of 20 semi-structured interviews[4] with key-informants, people I identified through public domain information and networking as being knowledgeable of UHF developments. A purposive sampling technique was adopted which allowed me to use my 'special knowledge or expertise about some group to select subjects who represent' a certain population (Berg, 2004: 36), knowledge I obtained through conducting a detailed literature review. I endeavoured to select a diverse sample by contacting people with a variety of different experiences, knowledge and beliefs regarding UHF. This included interviewing people from both *anti-fracking* and *pro-fracking* spheres. Additionally, I contacted academics researching a variety of different fracking issues (from social science to geology), as well as local government councillors, geological consultants and employees from regulatory bodies. This ensured a sample that had an adequate representation of people with a variety of differing political, economic and cultural viewpoints.

During (and post) data collection I transcribed interviews and coded them in preparation for analysis using coding methods developed by Miles et al. (2014). I then analysed the codes using thematic analysis to identify recurring themes for each interview question. Although I opted to use Miles et al.'s (2014) coding strategy, I generally followed Kvale's (1996) seven stages of the interview process for the duration

[4] In reality there were only 19 interviews as one interview involved two participants (see Chapter Four). However, for simplicity, the thesis will refer to either 20 participants or 20 interviews to avoid confusion. Ultimately, responses were received from 20 different participants.

of the research as a guide. These stages included: thematising, designing, sampling, interviewing, transcribing, analysing, verifying and reporting.

1.6. **Significance of the Research and Previous Work**

This thesis will provide an original contribution to academic understanding in the field of green criminology, but also to academic understanding of UHF, particularly in the UK. The thesis is original because there is very little research on UHF in the UK largely because the process is at an exploratory phase rather than a production phase of development. This research will therefore act as a starting point for academic discussions on the potential for environmental harm to occur from UHF in the UK.

The methodological approach to the thesis does not claim to be an original contribution to research on fracking because several studies have used the medium of interviews to collect data. Rinfret et al. (2014: 100) conducted 52 semi-structured interviews with agency staff and stakeholders to advance the understanding of 'fracking (regulatory) policy through state rulemaking processes' in Colorado, New York and Ohio in the US. Similarly, Ladd (2014: 297) conducted 35 in-depth, semi-structured interviews with 'residents, gas leaseholders, activists, industry spokespeople and professionals, business owners, scientists and others' in the Haynesville Shale region of Northwest Louisiana, US, in order to assess citizen attitudes toward fracking. Additionally, Carter and Eaton (2016: 395) conducted 55 interviews over a three-year period with policy makers, landowners, environmental consultants working for oil companies, and environmental non-governmental organisations (NGO's) in order to assess the regulatory response to unconventional fracking operations in Saskatchewan Province, Canada. Finally, Szolucha (2016)[5] studied the social impacts of fracking in Lancashire, UK,

[5] See also, Short and Szolucha (2017).

using a mixed-method approach of interviews and observations conducted over a 12-month period. This research focused specifically on social impacts (with findings analysing impact upon well-being and health, policing and intimidation, community impacts, democracy, gender relations, and the relationship between the gas company and local residents).

Despite this previous research, there is no research that conducts interviews on fracking in the UK with a specific focus on potential environmental harms. This is due primarily to the fact that fracking has not yet begun on a commercial scale.

1.7. **Conclusion and Structure of the Thesis**

The opening Chapter has sort to introduce the research and present a basic understanding of the methodological approach adopted. The thesis will now move on to examining the act of UHF in considerable detail in Chapter Two. This begins with an introduction to fracking in both a historical and global context followed by a discussion of the idiosyncratic traits that make UHF a unique hydrocarbon extraction technique. Chapter Two will also discuss the main areas from which environmental harm may occur as a result of UHF processes by examining the available literature (mainly overseas and offshore). This will result in the identification of seven different areas that went on to make up the interview questions for data collection, which includes: water aquifers; water resources; wastewater; seismicity; chemical usage; well integrity; and flaring.

Chapter Three will move on to discussions surrounding the theoretical literature review of the research by applying Treadmill of Production theory and eco-philosophy to the development of fracking in the UK. These two theories will then be integrated throughout the results (Chapters Five and Six), analysis (Chapter Seven) and conclusions (Chapter Eight).

Chapter Four moves away from the literature to present the methodological underpinnings of the research. This begins with a description of the methodological approach adopted addressing research questions, research design, sampling, locations and recording deliberations. The ethical considerations will then be presented prior to a deep analysis of the methodological technique of using interviews by discussing in detail: thematising; designing; sampling; interviewing (and telephone interviewing); transcribing; analysing; verifying; and reporting of interview data, following Kvale's (1996) approach to interviewing.

The results will be split into two digestible chapters. Chapter Five will consider participant responses to the three questions asked of them regarding water. These include the potential for fracking to; affect water aquifers; impact water resources; and problems associated with the generation, and disposal of, wastewaters. Chapter Six will consider the remaining four questions asked of participants regarding the potential for fracking to create environmental harm in the UK. These include the potential for fracking to: generate seismicity; what chemicals might be expected to be used in UHF processes; what effect fracking may have on the integrity of wells; and the potential use, and impacts of, flaring waste gases.

Following these results chapters, Chapter Seven will analyse each section in turn by drawing together the main findings of interviews and integrating the theoretical concepts of ToP theory and eco-philosophy to provide a unique analysis and understanding of why UHF is proposed in the UK in spite of several issues concerning the potential for different processes to generate environmental harm.

Finally, Chapter Eight will present the conclusions of the research by considering the research findings (section 8.1.), discussing the legislative and regulatory recommendations of the research (section

8.2.) and potential solutions (section 8.3.). The conclusions chapter will finish by outlining the original contribution to academic understanding and identifying directions for further research in the areas of green criminology and UHF (section 8.4.).

Chapter Two: Literature Review of Unconventional Hydraulic Fracturing

2.1. **Introduction**

This chapter paints a picture of the current situation with regards to UHF in both a global and national (UK) context. There were two reasons for doing this. Firstly, understanding UHF was pivotal in the ability to have discussions with key-informants to the UHF industry and to use the semi-structured interview technique to gain valuable information from participants during interviews based on their specific knowledge and expertise. Secondly, introducing the global, national and historical contexts of UHF will help the reader to understand what is meant by UHF in this thesis.

Sections 2.2. and 2.3. will introduce what is meant by the term hydraulic fracturing and will also provide a historical context examining how UHF developed as an oil and gas extraction technique according to academic literature. Section 2.4. will discuss the laws and regulations that affect UHF in the UK. Section 2.5. will integrate such legal aspects with academic research that identifies where environmental harms have occurred overseas, and this literature review will form the basis of the interview questions (see Chapter Four).

It is useful to note at this stage that the interview questions asked of participants were a direct result of the desk-based research carried out for this Chapter. There was no specific methodology used to conduct the literature review, other than attempting to find reliable information (largely academic research but also other relevant organisational literature) that addressed the process of UHF, in-line with the central research question:

What do key-informants understand to be the most salient concerns regarding the potential for unconventional hydraulic fracturing to cause environmental harm in the UK?[6]

2.2. **An Introduction to Hydraulic Fracturing**

There are different types of natural gas and different technological processes used to hydraulically fracture underground geological formations. It is vital to understand how this works because the discrepancies in these two variables (type of gas and composition of underground formation) determine production outcomes such as: how much oil or gas is available; how the resource is to be extracted; and the geological characteristics of the resource. This research is based in the UK and the natural gas available here is very different to the natural gas available in the United States because of different geological features (i.e. constituents of natural gas from shale. For more information, see: Goater, 2013; Stevens, 2013: 7).

Whilst unconventional hydraulic fracturing is often referred to as a new technology (Batley and Kookana, 2012: 425; Jaspal and Nerlich, 2014: 360), it could more accurately be described as the coming together of a number of technological innovations that have presented the US with a 21st Century *shale gas boom*. However, it must be noted that conventional hydraulic fracturing of different rock formations to release oil or gas is a process that can be traced back to at least the early 19th Century in the both the United States and the United Kingdom respectively.

2.2.1. Historical Hydraulic Fracturing

It is unclear exactly when and where onshore oil and gas production originated, but it is likely that natural gas from shale rock was being

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[6] See section 4.3. for a fuller discussion of the central research question.

extracted via conventional drilling techniques as early as the 1820’s in Fredonia, New York (US) (Prud’homme, 2014: 26). Attempts to extract natural gas from other rock formations such as sandstones and limestones could have been in operation prior to attempts in shale, but the first fracturing of shallow, hard-rock wells was occurring in the United States in the 1860’s with the use of (the then illegal substance) Nitroglycerin (NG) to search for oil in shale formations (Montgomery and Smith, 2010: 27; Prud’homme, 2014: 26). In the 1930’s, the idea of using acid alongside water to stimulate onshore wells began to emerge, but it was not until 1947 that the *modern fracfluid* (combination of water, sand and chemicals (in this case napalm gelled gasoline) was used to stimulate a well (Montgomery and Smith, 2010: 27). This was undertaken in Kansas (US) by Stanolind Oil and in 1949, the procedure was patented by Halliburton Oil Well Cementing Company (Montgomery and Smith, 2010: 27; Stretesky et al. 2014: 61).

Although hydraulic fracturing continued for many decades, conventional extraction techniques remained unprofitable and inefficient due in part to the low volumes of oil or gas produced for the expense of production. However, by the end of the 20th Century, Mitchell Energy had developed a chemical mixture for ‘slick-water fracturing’ to compliment financial investments which enabled the company to develop multi-stage horizontal fracturing of shale formations (Prud’homme, 2014: 29). This quintessential unconventional amalgamation (chemical mix and horizontal drilling) has changed hydraulic fracturing, turning an unprofitable conventional drilling technique into a profitable unconventional production process.

Although similar developments were happening in the UK in the 19th Century, the UK has thus far failed to exploit onshore oil and gas from shale relative to the developments of US shale production. The earliest reports of hydrocarbons date from 1836 in the UK and in

April 2013, the British Geological Survey (BGS) reported over 2,100 onshore drilled wells for oil and gas around the UK (Andrews, 2013: 4). Only one of these wells (Preese Hall, Lancashire) has been hydraulically fractured using the same unconventional techniques deployed in the US shale boom. The activities at the Preese Hall-1 well in 2011 led to minor seismic activity resulting in a government-induced one-year moratorium on unconventional hydraulic fracturing (Hawkins, 2015: 22). Since Preese Hall, strong public opposition to unconventional extraction techniques, coupled with the drafting and implementation of in-depth command and control legislation and regulation to govern the trade, has severely restrained a shale gas industry from kick-starting in the UK. This is a complete reverse of the US situation where the same industry is exempt from many federal environmental and social laws and regulations including: the Safe Drinking Water Act, the Resource Conservation and Recovery Act, the Emergency Planning and Community Right-To-Know Act (EPCRA), the Toxic Release Inventory of the EPCRA, the Clean Water Act, the Clean Air Act, the Comprehensive Environmental Response, Compensation and Liability Act and the National Environmental Policy Act (Brady and Crannell, 2012: 43; Kosnik, 2007: 2).

2.3. **<u>Shale Gas and Hydraulic Fracturing in the United Kingdom</u>**

2.3.1. <u>Conventional vs Unconventional</u>

The difference between conventional and unconventional hydraulic fracturing refers essentially to flow rate (United Kingdom Onshore Operators Group (UKOOG), 2013a). UHF occurs predominately in shale formations which is a low-permeability, high-porosity sedimentary rock meaning gas does not easily flow out of the rock into a well (Speight, 2013: 10). Shale therefore needs to be stimulated with chemical substances that ease the process, with sand to keep the fractures open allowing the gas to flow out more easily (thereby increasing the flow-rate) (Speight, 2013: 9-10).

Conventional wells do not normally need to be stimulated as gas flows out more readily than unconventional wells (UKOOG, 2013a). Technological advances such as multi-stage and horizontal hydraulic fracturing of shale are considered unconventional techniques, but they can also be interpreted as simply *new* techniques that allow unconventional sources of oil and gas to be exploited (such as shale), which cannot be extracted using conventional techniques (Montgomery and Smith, 2010: 32). Therefore, this unconventional type of hydraulic fracturing is a completely new technology in the UK with only the Preese Hall well having being successfully hydraulically fractured in an unconventional fashion.

2.3.2. Geological Formations

Onshore natural gas and oil reside in different types of geological formations in the UK. They (oil and gas) are fossil fuels that are the result of the slow decomposition of organic matter (animals and plants, for example) that are buried underground due to increased temperature and pressure over millions of years (Parliamentary Office of Science and Technology (POST), 2011: 2). Natural gas and oil are found onshore in shale formations, coal-beds and tight-sand deposits in the UK and the largest resources are estimated to be in the Upper Bowland Shale of the Pennine Basin (underlying Lancashire and Yorkshire), with further resources in the Wessex and Weald Basins (underlying Sussex, Hampshire and Dorset) (POST, 2011: 1).

2.3.3. Natural Gas

The composition of different gases that make up natural gas varies from place to place, just the same way that geological formations vary between locations. The main (and most common) component within natural gas however is methane with varying amounts of other gases such as ethane, propane, butane and carbon dioxide (C0^2). This can be seen in Table One:

Typical Composition of Natural Gas

Methane	CH_4	70-90%
Ethane	C_2H_6	0-20%
Propane	C_3H_8	
Butane	C_4H_{10}	
Carbon Dioxide	CO_2	0-8%
Oxygen	O_2	0-0.2%
Nitrogen	N_2	0-5%
Hydrogen sulphide	H_2S	0-5%
Rare gases	A, He, Ne, Xe	trace

Table One: *Typical Composition of Natural Gas* (NaturalGas.org, 2013).

Methane, which can make up 70-90% of natural gas, is not considered to be as harmful as C0^2 because it is more efficient when used (Karion et al. 2013: 4393). However, it is considered to leave at least a 20% greater footprint than C0^2 when it is extracted in UHF processes, because methane can escape from a well through leaks (such as an annular leak ‘which allows contaminates to move vertically either between casing or between casing and rock formation’ Al-Bajalan (2015: 4), in flow-back return fluids (Howarth et al. 2011a: 679) and in excess gases that return to the surface (these are not economically viable to use and are thus burnt-off through flaring (Glass, no date: 3). Wells have also been found to be leaking methane after they have been decommissioned and abandoned (Boothroyd et al. 2016; Dusseault et al. 2000).

Whilst the greenhouse gas (GHG) footprint of unconventional gas extraction may be as little as 11% (Hultman et al. 2011: 8) compared to conventional gas techniques, it is unclear whether unconventional natural gas extraction will positively or negatively affect GHG emissions (Howarth, 2014). Because the unconventional industry is in its infancy in the UK, there is a lack of research into GHG emissions from such techniques with (generally) industry insinuating it will act as a 'bridge fuel', safely guiding energy use from carbon-based fossil fuels to renewable energy (House of Commons Briefing Paper (HCBP), 2016: 25; Podesta and Wirth, 2009: 3). Conversely, opponents of fracking insinuate methane emissions are more damaging to the atmosphere than coal and oil and therefore cannot successfully act as a bridge fuel (Greenpeace, no date; Howarth et al. 2011b). Howarth (2014: 11) provides a solution to this argument by suggesting that:

> 'Society needs to wean itself from the addiction to fossil fuels as quickly as possible. But to replace some fossil fuels (coal, oil) with another (natural gas) will not suffice as an approach to take on global warming. Rather, we should embrace the technologies of the 21st Century, and convert our energy systems to ones that rely on wind, solar, and water power.'

Arguments like this debate on the impact of methane developed from hydraulic fracturing processes is one of the arguments that makes fracking a very controversial issue in the UK and this is largely because the UK is currently at the exploratory phase of shale gas development and, as a result, any subsequent impacts of methane on the environment are contestable. Furthermore, as will be seen in this chapter, the potential environmental impact of methane is not the only controversial issue. The extent to which a water aquifer can be contaminated, how wastewater is to be dealt with, and the impact of hydraulic fracturing processes on climate change are all issues that are certainly not settled within, not only the academic arena, but industrial and campaign arenas also. This research aims to address these important issues by obtaining the knowledge of key-informants who possess the relevant knowledge and experience to answer such important questions, persons who are arguably best placed to do so. As a result, the research will help to fill such gaps in the literature by tackling issues that are highly contested.

2.3.4. Dry Hydraulic Fracturing

One of the seminal environmental concerns related to UHF are the large quantities of water used in the process which pose great concerns for water scarce areas that are exposed to fracking (Short et al. 2015: 706). A single fracture may consume more than 500,000 gallons of water, and many wells receive several fractures, resulting in several million gallons of water used per well (Andrews et al. 2009: 24; Short et al. 2015: 705). As a result of this, there is a gap in the fracking market for new technologies that use less water to stimulate wells and some service providers in the US are now providing *dry fracking* where water is replaced by liquid $C0^2$ to make a new fracfluid based on sand, chemicals and liquid $C0^2$ (Praxair, 2016).

Some commentators also suggest that dry fracking can be executed purely with $C0^2$ (mixed with alcohol or liquid nitrogen) which limits both chemical and water usage (Harrison and Miklos, 2013: 29; see also: Kronenberg, 2014: 116; Royal Society and Royal Academy of Engineering (RSRAE), 2012: 20). Dry fracking is very much at the 'research and development stage' (Lavelle et al. 2013: 12) however, and the process only eliminates one form of environmental concern (water depletion) and does not solve problems of fugitive (or intended) emissions, noise, seismic activity, well integrity, environmental contamination, and other such concerns that are associated with UHF.

2.3.5. Resources vs Reserves

It is imperative to distinguish between the terms *resources* and *reserves* of onshore natural gas and oil in order to assess where the

UK sits in the global UHF outlook. It is also important in assessing the profitability, feasibility and legitimacy of extracting shale gas.

Resources, then, of natural gas, refer to 'the total amount of a commodity… that has been estimated to be ultimately available' (Speight, 2013: 160). Reserves of natural gas on the other hand refer to:

> 'well-identified resources that can be profitably extracted and utilized with existing technology, the estimated volume of gas economically recoverable from single or multiple reservoirs' (Speight, 2013: 160).

The BGS has conducted estimates into the quantities of reserves of onshore shale gas concluding that 4.7 trillion cubic feet (tcf) may be recoverable as an upper-limit based on comparisons between the Bowland Basin in Northern England and the Barnett Shale Basin in Texas (US) (Andrews, 2013: 3). 4.7 tcf is equivalent to approximately 1.5 years of UK gas consumption or 15 years of the UK's current liquefied natural gas (LNG) imports (House of Commons Energy and Climate Change Committee, 2011: 5). The Advanced Resources International (ARI) (2013: XI-2) report estimates total oil and gas reserves recoverable from shale at 26 tcf for the whole of the UK. To demonstrate the difficulty in recovering shale gas in the UK, these reserves are in comparison to much larger projected total resources of 623 tcf for shale gas and 54 billion barrels for shale oil (ARI, 2013: XI-2).

It is useful to take a broader outlook to fully understand the reasons behind government and industry backing of unconventional hydraulic fracturing in the UK, and of fossil fuel energy consumption in general. Different factors influence the dynamics of relationships that directly influence energy consumption and production (including UHF). One of these factors, for instance, is accelerating global population growth (Kotzé, 2014: 129). Statistics from the United Nations (2015: 2) indicate that the global population is increasing rapidly and expected to reach 9.7 billion by 2050 and 11.2 billion by 2100. Energy consumption is also set to rise in the immediate future with the United States Energy Information Administration (2013) predicting that 'world energy consumption will grow by 56% between 2010 and 2040, from 524 quadrillion British Thermal Units (Btu) to 820 quadrillion Btu.' This increase in energy consumption not only parallels forecasted population growth but parallels the increase in production (and therefore use of energy) identified by ToP theory.

2.4. <u>**Environmental Law: Command and Control Legislation and Regulation in the United Kingdom**</u>

Compared with other countries that are actively pursuing unconventional shale resources such as the US (Warner and Shapiro, 2013), Canada (Jefferies, 2012), Poland (Johnson and Boersma, 2013), and South Africa (Kotzé and Goosen, 2014), the UK has a substantial legislative and regulatory framework most of which comes from the *Petroleum Act 1998* and the *Infrastructure Act 2015*. The two main reasons for this development are likely to be the result of environmental and health related disasters in the US (DiGiulio et al. 2011; Jackson et al. 2014), alongside the seismic tremors that occurred at the Preese Hall-1 well in Lancashire (UK) in 2011 (Green et al. 2012; Hawkins, 2015: 11). According to ARI (2013: XI-8):

> 'the timing of the earthquakes corresponded with fluid injection and continued for several hours after injection ceased. The largest earthquakes were relatively small, measuring magnitudes of 2.3 and 1.5 on the Richter scale.'

The fact this was the very first horizontal hydraulic fracture in the UK must have alarmed the UK government, questioning the safety of the fracking process, because a moratorium was implemented by the government in 2011 and lifted by Edward Davey, (then) Secretary of

State (SoS) for the Department of Energy and Climate Change (DECC) in December 2012 (Alessi and Kuhn, 2012). In 2011, when these tremors took place, there was no legislative or regulatory restrictions or requirements for certain fracking concerns such as seismic activity (Hawkins, 2015: 12). As a result, the government have since introduced command and control legislation and regulation in an attempt to monitor and control the industry in order to safeguard human health and prevent environmental degradation (through the *Infrastructure Act 2015*). This does not mean however, that the legislative and regulatory measures are perfect, the reasons for which will now be discussed.

2.4.1. <u>The Petroleum Act 1998</u>

The first piece of legislation that had a substantial effect on the extraction of sub-surface resources in the UK was the *Petroleum (Production) Act 1918* (Hansard, 2005). This was enacted following the First World War with the intention of securing a supply of oil for the UK due to difficulties in importing oil at that time (Abdo, 2010: 11). The Act 'prohibited exploration and production of petroleum resources other than by the Crown or under licence from the Crown' (UKOOG, 2013b: A1). With little early commercial success, the *Petroleum (Production) Act of 1934* was enacted which vested proprietary rights for petroleum in the Crown. According to Anenih (2003: 2) 'the new licensing regime was no longer based on the need to prohibit unlicensed exploration and exploitation of petroleum resources, but on the transfer of the proprietary rights of the Crown' making it easier to search for petroleum (this act stood until it was repealed due to the coming into force of the new 1998 Act). The same rights were applied from the *Petroleum (Production) Act 1934* to the *Continental Shelf Act of 1964* making rights to petroleum the same both onshore and offshore (UKOOG, 2013b).

The *Petroleum Act 1998* vested all rights to the United Kingdom's petroleum resources in the Crown (OGA, 2012) both onshore, offshore and in Crown land itself. The Act also gave the SoS power to grant licences enabling persons to search, bore for and get petroleum (*Petroleum Act 1998*, s.3(1)) as well as providing ancillary rights under the *Mines (Working Facilities and Support) Act 1966.* Such rights enabled a licence holder to do certain things related to extracting hydrocarbons such as erect buildings, lay pipes, and other such construction works necessary to carry out searching and boring for petroleum (*Petroleum Act 1998*, s.7.1 and s.7.3).

The *Petroleum Act 1998* secured access to hydrocarbons beneath Crown land devolving power to the SoS to grant licences to persons wishing to search and bore for such hydrocarbons. This can be viewed as an anthropocentric approach to the notion of sustainable development that is embedded within UK environmental law. The UK government believes that sustainable development can be achieved by stimulating economic growth whilst protecting the environment in a way that does not affect 'the ability of future generations to do the same' (Department for Environment, Food and Rural Affairs, 2015). In reality, this cannot be achieved because under the capitalist mode of production, economic growth requires the maximisation of profits that is achieved at the expense of the environment through ecological disorganisation outlined in ToP theory (see Chapter Three). Legislative efforts to protect the environment are therefore exploitative (Frawley, 1994) as they 'facilitate the extraction and processing of particular resources' guaranteeing long-term access to sites for the purposes of commercial activity (Halsey and White, 1998: 362).

Whilst the *Petroleum Act 1998* safely secured the rights to hydrocarbons in the Crown, it did not specifically intend to control and regulate UHF. The UK government passed the *Infrastructure Act*

2015 which specifically referred to hydraulic fracturing in Part 6 of the Act (Energy).

2.4.2. The Infrastructure Act 2015

The *Infrastructure Act 2015* is the main statute applicable to UHF containing both the legislative and regulatory frameworks that control and regulate the actions of licence holders searching and/or boring for petroleum resources. The *Infrastructure Act 2015* is designed to protect human health and the natural environment whilst simultaneously enabling the sustainable development of the UHF industry for the benefit of fracking companies, local communities, and the government (through increased employment and increased energy security) (HCBP, 2016). Despite these efforts, this section will reveal that the legislative and regulatory framework for this type of industry is not sufficient in adequately protecting humans and the environment. This is argued by drawing on evidence of the consequences of extracting shale gas around the world and linking this information with specific, relevant sections of the *Infrastructure Act 2015*.

2.4.2.1. *Water: Fracfluid*

Fracfluid is necessary in UHF processes due to the low-permeability of shale rock which makes it very difficult for trapped hydrocarbons to escape easily. Whilst shale rock can be hydraulically fractured, this is not usually enough to allow gas to flow out of the fissures and up to the surface. Fissures need to be kept open by using sand which acts as a proppant (by holding induced fractures open for longer) within fracfluid. This fracfluid is a mixture of water, sand and chemicals which are injected into wells at high pressure (Prud'homme, 2014: 37).

Promoters of UHF make it aware that the chemicals used in fracfluid make up only a very small percentage of the mixtures overall composition, usually less than 1% (Faulkner, 2014: 86; Prud'homme, 2014: 37; Speight, 2013: 80). Although this is correct, the low percentage still equates to huge measures of chemicals when the large volumes of fracfluid used in the process are realised. Exact quantities of water used for fracking are variable and uncertain (Gleick et al, 2014: 67) and can be dependent upon a variety of factors including: the company; the location of the well; the amount of times a lateral extension is hydraulically fractured[7]; and the number of lateral extensions per well. However, Brzycki et al. (2014) note that:

> 'Each drill site requires between 3 and 5 million gallons of water per frack. Based on approximately 1,500 horizontal wells fracked in 2011, Pennsylvania used about 12-20 million gallons of water per day for Marcellus Shale drilling, which represents approximately 0.5-0.8% of the 9.5 billion gallons of water the state uses daily.'

In the UK, such large quantities of water could pose a threat to local water supplies particularly in drier areas (Hawkins, 2015: 11; Marshall, 2014: 3). However, the UK government has legally enabled large quantities of fracfluid to be used in hydrocarbon extraction processes under s.50 of the *Infrastructure Act 2015 (IA 2015)*, which states the definition of what constitutes a hydraulic fracture:

> (1) "Associated hydraulic fracturing" means hydraulic fracturing of shale or strata encased in shale which—
>
> > (a) is carried out in connection with the use of the relevant well to search or bore for or get petroleum, and
> >
> > (b) involves, or is expected to involve, the injection of—

[7] When discussing the onshore UHF industry in the US, Shadravan et al. (2015: 2) suggest that 'industry is today capable of performing up to 60 stage frac jobs in unconventional wells.'

> (i) more than 1,000 cubic metres of fluid at each stage, or expected stage, of the hydraulic fracturing, or
> (ii) more than 10,000 cubic metres of fluid in total.

This definition means that if a hydraulic fracture falls outside of these boundaries (i.e. less than 1,000 cubic metres of fluid per stage or less than 10,000 cubic metres of fluid in total), companies ‘may be able to bypass the limited legal controls that have been retained’ (Campaign to Protect Rural England, 2015). This provides a substantial loophole in the successful application of control regulation to unconventional hydraulic fractures that fall outside of this boundary.

Cuadrilla Resources are the only company to conduct an onshore UHF operation in the UK (Pool, 2011: 90). As a result, discussions on fracking chemicals in the UK must start with what was used by Cuadrilla Resources. A comparison will then be made with the substances used in many wells in the US where UHF operations are much more advanced. According to Cuadrilla Resources (no date), 99.95% of the fracfluid used at the Preese Hall-1 well was water and sand (97.93% water and 2.023% sand (constituted of Congleton sand at 0.473% and Chelford sand at 1.550%). The remaining 0.043% comprised Polyacrylamide Emulsion used as a friction-reducer to lessen the pressure required to pump down the well (Cuadrilla Resources, no date).

The Environment Agency (EA) is the environmental regulator responsible for regulating the substances used in hydraulic fracturing as can be seen in s.50(5)8 of the *Infrastructure Act 2015*:

> The substances used, or expected to be used, in associated hydraulic fracturing – (a) are approved, or (b) are subject to approval, by the relevant environmental regulator.

> An environmental permit has been given by the relevant environmental regulator which contains a condition that requires substances used in associated hydraulic fracturing to be approved by that regulator.

This is one of eleven regulations that must be met before the SoS may approve a licence consenting to hydraulic fracturing. The EA is the environmental regulator that assesses the chemicals used in the fracking process on a case-by-case basis (DECC, 2014a: 4). For example, the EA have approved non-hazardous substances to be used by Cuadrilla Resources in hydraulic fracturing operations which includes: sodium salt (for tracing fracfluid), hydrochloric acid, and glutaraldehyde biocide (to cleanse water and remove bacteria) (Cuadrilla Resources, 2016), although Cuadrilla did not report the use of these in their Preese Hall-1 well (Cuadrilla Resources, no date).

Chemical usage is much more complex in the US where operators (until May 2015) were not required by law to disclose the composition of fracfluid due to UHF being exempt from several federal acts and regulations (Brady and Crannell, 2012: 43; Kosnik, 2007: 2; see section 2.1.1.). Companies are now required to publicly disclose fracking chemicals under the *US Fracturing Responsibility and Awareness of Chemicals Act 2015* (known as the FRAC Act) (Congress.gov, 2015). Whilst some companies display the chemical composition of their fracfluid online (see Appendix Two), many now use FracFocus which is the US National Chemical Registry for hydraulic fracturing (FracFocus, 2018).

During the research, the US industry leader Halliburton listed all the chemicals used in Halliburton operated UHF wells globally on their website[8]. Appendix Two displays the chemicals used in fracture fluid

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[8] At the time of submission of this thesis, to the best of my knowledge, Halliburton have removed this information from their website. It is likely that they now use a chemical registry to display

in ‘Pennsylvania WaterFrac Formulation’ (Halliburton, 2016) which contains water (92.23%), sand (6.24%) and ‘fluid system’ chemicals (1.53%) (Halliburton, 2016). In stark contrast to the non-hazardous chemicals used by Cuadrilla at the Preese Hall-1 well, Halliburton claim to use eight hazardous chemicals in this example of fracking fluid according to their Material Safety Data Sheets (MSDS) for hydraulic fracturing (see Appendix Two). This comparison represents the difference between chemical usage in the UK and the US and clearly demonstrates the maturity of US fracking technology over the UK.

The regulation of fracking fluid in the UK from the EA can be seen as successful in controlling the substances used in fracking operations. The EA can pose controls under the Mining Waste Directive (2006/21/EC), the Environmental Permitting (England and Wales) Regulations 2010, and the Groundwater Daughter Directive (2006/118/EC) (EA, 2013). This does not mean, however, that chemicals used in the process (particularly in the future where more and different chemicals may be used) do not present dangers to human health and the environment. The EA (2013: 10) recognises that ‘the chemicals used to make up the fracturing fluid are delivered in concentrated form and need to be stored and handled appropriately. There is the potential for spillages at the delivery, storage and mixing stages’ and that the harmful consequences of this could result in ‘contamination and loss of resources, injury, ill health or death, (and) loss of or damage to a habitat’ (EA, 2013: 10).

Fracfluid, then, clearly creates risks that exacerbate the chances of creating social and ecological harm. The ways in which fracfluid are dangerous to human health and the environment are largely

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such information. The information on this page was obtained on their website on 15th February 2016 (see Appendix Two) when the company displayed chemicals on their website (instead of using a registry).

concerned with risks to groundwater and to water aquifer contamination which will now be discussed.

2.4.2.2. *Water Aquifer Contamination: Well Integrity and Well Leakage*

In the UK, water for domestic and industrial use comes from a range of sources including lakes, reservoirs and other surface waters, as well as from water aquifers that exist in contained or uncontained resources a few hundred feet underground (Geological Society, no date: 2). These water resources are the result of rainfall that has filtered down through the ground and is stored in the spaces between permeable rocks (EA, no date: 7). In terms of quantity, according to the BGS (no date):

> 'Groundwater supplies water to about 27% of the population across the UK. This proportion varies widely depending on the underlying geology, with the highest proportion of drinking water being supplied by groundwater in the south-east of England (over 70%). The current estimated groundwater usage for public supply by regions (is): England, 35%; Wales, 2%; and Scotland, 7%.'

Water aquifers[9], then, clearly represent an important source of water usage for the UK but this is not the only concern with regards to water and hydraulic fracturing. The depletion of water resources from groundwater to use in fracfluid (Stuart, 2012), the migration of released methane into water aquifers contaminating water (Osborn et al. 2011), and the pollution of aquifers from the use of fracfluid containing harmful chemicals (Mandel, 2013) also arise in the literature as causes of concern.

In order to address this, the UK government defined deep-level land in s.43 of the *Infrastructure Act 2015* as 'any land at a depth of at

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[9] A form of groundwater (for more detail, refer to the definitions of *groundwater* and *water aquifer* contained within the glossary).

least 300 metres below surface level,' which means that a person (with the required permit) has the right to use deep-level level only at a depth of 300 metres or greater, and this depth is below water aquifers[10] thereby ensuring their protection through legislation. Similarly, in order to limit the risks associated with contamination of a water aquifer from extracting resources from deep-level land, the UK government placed a condition that prohibits associated hydraulic fracturing from taking-place at depths of less than 1000 metres in the *Infrastructure Act 2015.* Operations conducted at depths greater than 1000 metres can only take place if a hydraulic fracture consent is issued by the SoS upon the meeting of regulations that accompany the license. This is clarified in s.50 4A(1)(a) and (b):

> (1) The Secretary of State must not issue a well consent that is required by an onshore licence for England or Wales unless the well consent imposes—
>
> > (a) a condition which prohibits associated hydraulic fracturing from taking place in land at a depth of less than 1000 metres; and
> > (b) a condition which prohibits associated hydraulic fracturing from taking place in land at a depth of 1000 metres or more unless the licensee has the Secretary of State's consent for it to take place (a "hydraulic fracturing consent").

Water aquifers in the UK reside a couple of hundred feet below surface level (fluctuating between times of floods and droughts) (EA, no date: 12). The fact hydraulic fracturing is prohibited at depths of below 1000 metres means there is a great distance between where

[10] In the UK, water aquifers generally exist between 100 and 200 metres below the earth's surface. According to the UK Groundwater Forum (no date: 1) 'most groundwater in an aquifer is slowly circulating in the upper 100 to 200 metres of the saturated zone. But fresh water can penetrate to depths of more than 2 kilometres although at such depths groundwater is generally mineralised with solutes, particularly sodium and chloride, and is too saline for potable use.'

the fracturing of shale rock takes place, and the location of the water aquifer. This makes the contamination of water from migrating methane and fracfluids from underground shale formations to water aquifers highly unlikely (Davies et al. 2012; RSRAE, 2012: 34). In addition, shale formations in the UK exist at depths of between 2-5km below surface level (Geological Society, no date: 2), which is far below water aquifers. A study assessing several thousand onshore hydraulically fractured wells in five different US shale plays found that the probability of a fracture extending at a height of greater than 350m (from the fracture location) is less than 1% (with the maximum height being 558m in that particular study) (Davies et al. 2012: 4), which again ensures fissures should not extend far enough to get close to water aquifers. The conclusion here, then, is that it is extremely unlikely that water contamination would occur as a result of methane migration of chemicals from the location of fissures underground, up through the several different geological formations.

There is, however, a risk of water aquifer contamination if the casing of the well fails at a point that runs through a water aquifer. The problem of the integrity of wells has been of significant environmental and human health concern in the United States (Jackson et al. 2014: 337) where research ‘has demonstrated that proximity to unconventional gas wells is associated with elevated concentrations of methane in groundwater aquifers’ (Ingraffea et al. 2014: 10955). Both Osborn et al. (2011) and Jackson et al. (2013) found positive relationships between thermogenic methane concentrations in private water wells in Pennsylvania and the proximity of those wells to the nearest unconventional gas well (in: Ingraffea at al. 2014: 10955). Similarly, Pétron et al. (2012) and Karion et al. (2013) both found increased atmospheric levels of thermogenic methane (found sub-surface) high above the grounds of conventional and unconventional gas wells in Colorado (Pétron et al. 2012: 4) and the Uintah County oil and gas field, Utah (Karion et al. 2013: 4394).

The most likely reason for these results was the sub-surface migration of thermogenic methane from leaking wells (i.e. wells with poor integrity due either to damage from the high pressures associated with the process, or poor design and/or monitoring of wells). As Ingraffea et al. (2014: 10955) explain:

> 'A leaking well, in this context, is one in which zonal isolation along the wellbore is compromised due to a structural integrity failure of one or more of the cement and/or casing barriers. Such loss of integrity can lead to direct emissions to the atmosphere through one or more leaking annuli and/or subsurface migration of fluids (gas and/or liquid) to groundwater, surface waters, or the atmosphere. Cement barriers may fail at any time over the life of a well for a number of reasons, including hydrostatic imbalances caused by inappropriate cement density, inadequately cleaned bore holes, premature gelation of the cement, excessive fluid loss in the cement, high permeability in the cement slurry, cement shrinkage, radial cracking due to pressure fluctuations in the casings, poor interfacial bonding, and normal deterioration with age.'

Additionally, *Sustained Casing Pressure* (SCP) is a term used to describe pressure that is built-up over time (Shadravan et al. 2015: 3) on one or more casings of a well (see Appendix Three for a visual representation of a multi-barrier system (MBS). This pressure is not directly imposed by the operator, nor by temperature fluctuations within a well (International Association of Drilling Contractors, 2014; Rocha-Valadez et al. 2014; Wojtanowicz et al. 2001) but can be caused by a number of problems. The most likely causes are tubing and casing leaks within a well and/or poor cementing[11] (Bourgoyne et al. 2000: 16). SCP is important in the context of UHF because it may cause a well-blowout (Bourgoyne et al. 2000: 38; Wojtanowicz et al. 2001: 4). It may also provide a pathway for substances and

[11] There are also many reasons why tubing and casing leaks may occur and difficulties with cementing wells. For more information, see Bourgoyne et al. (2000: 16-19).

other geological matter (existing within a well) to leak from the well into the environment (Davies et al. 2014: 241). The environmental significance of this is explained by Wojtanowicz et al. (2001: 4):

> 'Sustained casing pressure represents a potential risk of losing hydrocarbon reserves and polluting the water column with leaking hydrocarbons. Although 90% of sustained casing pressures are small and can be contained by casing strength, it is still potentially risky to produce or, more importantly, to abandon such wells without eliminating the pressure.'

SCP can lead to environmental harm within an UHF operation because it may lead to a loss of well integrity (Jackson et al. 2014: 337). It is important to note here, however, that a single barrier failure does not always result in contamination if that barrier does not come into contact with the environment and outer barriers are subsequently successful in containing SCP leakage (Jackson et al. 2014: 338 King and King, 2013). Furthermore, there have been some developments in the creation of casing technologies that are expandable and therefore more adept at withstanding high-pressures which would ultimately reduce the risk of SCP and any associated wellbore leaks (Kupresan et al. 2013).

Rates of SCP (that have the potential to lead to well integrity failure and ultimately, environmental contamination) vary onshore and offshore and can also differ between regions and companies. In Alberta, Canada, companies reported that 3.9% of >315,000 wells showed evidence of SCP with one region reporting 15.3% (Watson and Bachu, 2009). Although 3.9% appears to be a small percentage, of SCP occurrence, this still amounts to approximately 12,285 wells which creates a high amount of risk of environmental contamination. Leakage occurs as a result of SCP which can lead to well integrity failure. Erno and Schmitz (1996) measured surface casing leakage for 1,230 oil and gas wells near Lloydminster, Canada, and found that across their dataset, 23% of wells showed surface and soil gas leakage. This data, however, includes conventional oil and gas wells but more recent data has suggested that unconventional wells are 3 to 4 times more likely than purely vertical wells to show signs of SCP and Gas Migration at <30% of 4,600 wells for each day (Watson and Bachu, 2009).

Although all wells are subject to decommissioning and essentially *plugging* the well to contain any potential substances returning to the surface, many wells fail eventually because concrete and steel casings erode over time, and especially after they have been subjected to high-pressure and high-volume of fluid during the productive lifetime of the well. The fact that many wells fail over time is supported by academic literature (Jackson et al. 2014; Kang et al. 2014; McCoy and Saunders, 2015: 10-11; Watson and Bachu, 2009). Jackson (2014: 10902) sum this up by stating that:

> 'Faulty casing and cementing cause most well integrity problems. Steel casing can leak at the connections or corrode from acids. Cement can deteriorate with time too, but leaks also happen when cement shrinks, develops cracks or channels, or is lost into the surrounding rock when applied. If integrity fails, gases and liquids can leak out of the casing or, just as importantly, move into, up, and out of the well through faulty cement between the casing and the rock wall.'

The consensus in the UK appears to be that better command and control legislation and regulation of the industry will result in better well integrity through a process of permitting and monitoring (HCBP, 2016: 27-29). S.50 of the *Infrastructure Act 2015* requires an independent inspection of the integrity of wells to be undertaken by the Health and Safety Executive (HSE) who are an independent regulatory body. Operators must notify the HSE of the well design and operation plans prior to conducting UHF (21-days before drilling) 'to ensure that major accident hazard risks to people from well and well related activities are properly controlled' (HSE, no date:a).

Whether such regulatory activity will be successful in preventing or limiting environmental harm is yet to be seen due to the infancy of UHF onshore in the UK.

2.4.2.3. *Wastewater and Flaring of Excess Gases*

UHF uses high-volumes of fracfluid. Part of this fracfluid returns to the surface through the wellbore and part of the fluid remains underground. There are no publicly available consistent figures on the percentage or volumes of fluid that remain underground after unconventional hydraulic fracturing operations finish, but Brzycki et al. (2014) estimate that only 10%-30% of the total water used returns to the surface, the rest of which remains deep underground. However, others suggest that much of the fracturing fluid returns to the surface 'over the lifetime of the well' (Howarth et al. 2011a: 272). The reality is that returning fluid will vary from place to place, just as fracfluid itself will vary from place to place (Mohajan, 2012).

Both the flow-back water and produced water that return to the surface during or after UHF operations is of a different configuration to the original composition of the fracfluid after it has been used in the production of natural gas (Olsson et al. 2013: 3896). Alongside the make-up of fracfluid that includes water, sand and chemicals, produced water can also contain:

> 'dissolved and suspended organics, measured as total oil and grease; suspended solids, such as formation solids, corrosion and scale products, and bacteria; production chemicals, which may contain proppants, friction reducers, biocides, and corrosion inhibitors from the hydraulic fracturing fluid; naturally occurring radioactive material, specifically barium and radium isotopes; and total dissolved solids (TDS), including hardness and heavy metals' (Shaffer et al. 2013: 9573).

Therefore, the constituents of produced water can vary over time because of the variety of materials and substances used in UHF operations, and the complex geological make-up of underground formations. This produced water must be disposed of safely in the UK because it is considered as mining waste by the EA under the European Union (EU) Mining Waste Directive 2006/21/EC (Bryden et al. 2014: 30). Fracfluid mining waste is also affected by the Water Framework Directive (requiring an environmental permit as well as pre-treatment, before discharge into a well), and the Radioactive Substances Regulation (for wastewater containing Naturally Occurring Radioactive Material (NORM) requires another environmental permit) (RSRAE, 2012: 21). Produced water can either be disposed of by treatment at a water treatment facility (BGS, 2012: 15), by re-injecting the fluid back into the well (RSRAE, 2012: 14) or by discharge to nearby surface waters (BGS, 2012: 15). Treatment requires keeping flow-back water in retention pits which can 'be used to store additional make-up water for drilling fluids or to store water used in the hydraulic fracturing of wells' (BGS, 2012: 15). Retention pits are temporary solutions to dealing with the produced water that returns to the wellbore in the first few days and weeks of hydraulic fracturing.

These treatment processes however, all have associated problems. Discharge into surface water is 'generally unfeasible due to the quality of the water to be disposed' of (BGS, 2012: 15). Similarly, retention pits have been controversial in the United States because of the evaporation of substances from such water into the atmosphere (Brown, 2007: A76) and the effects that this has on atmospheric conditions. Re-injecting fluids into wells has also been directly related to earthquakes in the United States (Ellsworth, 2013; Hough, 2014) which is a concern for the underground environment and for public health and infrastructure damage. Despite this, the re-injection of wastewater into wells has been described as 'the most common and economically viable solution to deal with flow-back wastewaters in the US' (Haszeldine et al. 2016).

In the UK, the EA will not condone the re-injection of flow-back water (EA, 2017: 2). However, they may condone the re-injection of *produced* water for disposal purposes into wells which are classed as permanently unsuitable. As the EA (2015: 39) state:

> 'Where the produced water contains a concentration of NORM waste above the out of scope values, this can be re-injected for disposal at the original site or at a different site into geological formations from which hydrocarbons have been extracted, or which for natural reasons have been designated by us as permanently unsuitable. This is the best environmental option to minimise the exposure of the public to ionising radiation from the disposal of NORM waste… To do this you (operator) will need a permit for a groundwater activity and radioactive substances activities. Where the produced water contains below out of scope NORM waste values it is not considered radioactive waste but can be re- injected for disposal at the original site under a groundwater activity permit.'

The disposal of produced water and flow-back water is clearly a problem for operators and the EA alike. The most appropriate way to deal with such waste would be to treat it appropriately at a water treatment facility before the water is released back into the environment (through surface waters) or re-used. However, treating water is a complex and often expensive process (Gregory et al. 2011) that involves storage (in retention pits and in the transportation of the water to a treatment facility) which poses several dangers to ground surface if accidents occur along the way (this is before the water is treated). Gregory et al. (2011) note that wastewater treatment facilities have not been an adequate or sustainable approach for managing flow-back water in the US, which may explain the high rates of re-injection of fluid into depleted wells as a disposal technique.

Another form of waste created by UHF processes is excess methane which is often flared (burnt off) into the atmosphere. Venting and flaring are used as terms to explain the intentional release of natural gas into the atmosphere mainly during the drilling of a well (and less so during production). This gas is not deemed to be economically viable, and thus needs to be disposed of (Glass, no date: 3). Flaring is a very popular technique in the United States (World Bank, 2016) and is planned to be used in the UK (HCBP, 2016: 26). This is despite flaring being reported as the largest GHG emissions contributor in the hydraulic fracturing process (Jiang et al. 2011: 6). Although methane (the main compound vented or flared) is efficient as an energy resource 'that produces more energy per carbon dioxide molecule formed than coal or oil (177% and 144% respectively)' (Karion et al. 2013: 4393), it is a GHG that is estimated to be '25 times more potent than carbon dioxide over a 100-year time horizon' (Karion et al. 2013: 4393). This seriously undermines the ability of natural gas to act as a bridge fuel from carbon-based resources to renewable resources of energy as the UK government anticipates (HCBP, 2016: 3; Stephenson et al. 2012).

When concluding about the use of venting and flaring of natural gas, Jiang et al. (2011: 8) note that 'green completion and capturing the gas for market that would otherwise be flared or vented, could reduce the emissions associated with completion,' but this does not consider the feasibility of transforming uneconomical natural gas into gas suitable for use at any level. The UK government assessed that 'flaring and venting of methane should be reviewed to keep fugitive emissions as close to zero as possible' (HCBP, 2016: 26; House of Commons Energy and Climate Change Committee, 2013: 5). This is however, a contradictory statement, because burning an extremely potent natural gas as the primary means of disposing of that gas is a significant contributor to GHG emissions (Jiang et al. 2011; Karion et al. 2013) and is therefore not a suitable technique for keeping fugitive emissions close to zero.

The UK is committed to reducing its emissions after signing the Paris agreement in December 2015, a global commitment shared by over 200 countries in an attempt to keep global temperature increases below 2 degrees Celsius (Casson et al. 2015). The UK is also legally committed to climate change reduction targets under the *Climate Change Act 2008*. S.1(1) of the Act states that:

> It is the duty of the Secretary of State to ensure that the net UK carbon account for the year 2050 is at least 80% lower than the 1990 baseline.

The extent to which emissions from hydraulic fracturing operations (particularly of methane leakage, flaring and venting) will affect the environment is contestable. It is very difficult to predict the extent to which fracking in the UK will impact upon climate change because the UK is currently at the exploratory phase of shale gas development rather than a production phase and, consequently, attempts to predict such impacts are inherently subjective. However, this does not mean that the impact of fracking operations on the climate is not extremely important. Conducting interviews with key-informants will help to forge a greater understanding of the extent to which fracking operations may influence the climate.

Another concern with unconventional hydraulic fracturing is seismicity that can occur by injecting fluids underground (at production stage or by disposing of wastewater), or by the initial fracturing of rock underground.

2.4.2.4. *Seismicity*

Earthquakes, earth tremors and other forms of seismic activity are perhaps the most controversial problems to arise with regards to

UHF in the UK as a result of the seismic activity induced by Cuadrilla Resources at their Preese Hall-1 well in 2011. A number of small micro-earthquakes were triggered as a result of UHF operations, the largest earthquake measuring 2.3 magnitude on the Richter scale (Green et al. 2012: 1). In the United States, it has been found that the deep re-injection of wastewater 'has caused significantly higher-energy earthquakes' than those earthquakes induced as a result of injecting fluid to stimulate shale rock in the production stage (Jackson et al. 2014: 344). 21 earthquakes of 3.0 magnitude or greater have occurred per year steadily in the central regions of the United States from 1967 to 2000, but from 2001 to 2011, earthquakes of these magnitudes have increased to ~100 per year with 188 in 2011 alone (Jackson et al. 2014: 345). This increase corresponds with the increased use of deep-water injection of wastewater used in oil and gas operations in the central United States around the same period (Ellsworth et al. 2015; Jackson et al. 2014: 345).

Zoback (2012: 3) has proposed five steps to reduce the likelihood of seismic reoccurrence, the first of which is to 'avoid injection into active faults' or faults in brittle rock. Appendix Four demonstrates the faults that exist in the Bowland shale in Lancashire (the location of the Preese Hall-1 well) which has been described as a 'heterogeneous, relatively impermeable, stiff and brittle' (Green et al. 2012: 2) area of shale rock and that earthquake activity here was the direct result of fluid injection into a fault zone (Green et al. 2012: ii). Zoback (2012: 39) denotes that there have been no earthquakes that have caused serious injury or significant damage as a result of such fluid injection. Despite this, seismic activity does have the potential to cause damage to well integrity and 'tests carried out after Cuadrilla's second fracturing stage… revealed deformation of the Preese Hall well casing' (RSRAE, 2012: 45).

This thesis will contribute to academic literature on the environmental effects of fracking by interviewing key-informants who are highly knowledgeable about different fracking issues. Doing this at a time when the UK is at an exploratory phase of development serves to identify what the most salient concerns are with regards to the potential victimisations that may occur as a result of hydraulic fracturing processes. This is a precautionary approach to analysing victimisation as opposed to research that identifies victimisations after they have already occurred (a reactive approach). This precautionary approach to assessing environmental harm is undoubtedly a more advantageous approach to research than quantifying and reacting to environmental harm that has already occurred. This premise is an underlying core rationale for this research that has been discussed in Chapter One (section 1.1.) and will be discussed further in Chapter Four (section 4.2.).

2.5. **Conclusion to Literature Review**

This chapter has identified several social and environmental victimisations that may result from fracking in the UK by drawing upon research in countries that are currently at the production stage of UHF development. The main issues that have arisen in the literature are presented in Table Two:

Water	**Other**
The potential for **water aquifer** contamination	The creation of **seismicity**
The use of **water resources** for fracfluid	The **chemical** constitution of fracfluid
Dealing with **wastewater**	The impact of UHF processes on **well integrity**
N/A	The use and impact of **flaring**

Table Two: *Broad Categories to Make-Up Interview Questions*.

These seven issues were formulated into interview questions for this research to gain a deeper insight into hydraulic fracturing processes from the knowledge and experience of key-informants. The interview questions can be seen as follows:

1. There is conflicting research on the extent to which fracking may or may not affect water aquifer's. What, if any, impact do you believe fracking has on water aquifers?
2. What impact, if any, do you believe fracking will have on the UK's water resources?
3. There is conflicting research on the amounts of water that return to the surface during and after fracking operations. However, there is an agreement that much water does return to the surface at some point. With this in mind, how do you believe this wastewater will be disposed of in the UK?
4. What impact, if any, do you believe fracking has on 'seismicity' or 'earthquakes'?
5. Although chemicals used are likely to vary from company to company and from location to location, could you explain your knowledge with regards to what substances are expected to be used in hydraulic fracturing fluids?
6. There is conflicting research on the extent to which fracking wells may or may not leak during production of fracking wells and after the de-commissioning of fracking wells. Can you explain your knowledge of well integrity related to fracking?
7. In the United States, excess gases have been disposed of through flaring such gas into the atmosphere. Firstly, do you believe this method will be used in the UK and secondly, what impact, if any, do you believe flaring will have on the environment?

Before moving on to discuss the methodology of the research in more detail (see Chapter Four), the following chapter will introduce and discuss the two main theoretical underpinnings of the research, Treadmill of Production theory, and eco-philosophy.

Chapter Three: Literature Review (Theory)

3.1. <u>**An Introduction to the Literature Review**</u>

The literature review exists in two separate Chapters of the thesis (Chapter Two and Chapter Three). The previous chapter provided a critique of the unconventional hydraulic fracturing literature in both national and international contexts in terms of its ability to provide social, economic and political gains on the one hand, and human, non-human and ecological harms on the other. This chapter provides a critical overview of the green criminological literature, the stance from which this thesis will evaluate hydraulic fracturing in the UK focussing specifically on the understanding and application of Treadmill of Production theory and eco-philosophy.

Whilst Chapter Two sought to provide a detailed background to the technique of UHF, this chapter aims to outline the theoretical underpinnings of the research which encompass Schnaiberg's (1980) Treadmill of Production theory and Halsey and White's (1998) interpretation of anthropocentrism, biocentrism and ecocentrism which will come under the collective term of eco-philosophy. Additionally, the nature of the research can be seen to fall under the perspective of green criminology and debates (particularly surrounding the legality of UHF) will often refer to this term. As a result, green criminology will also be discussed in detail within this chapter and integrated regularly throughout the remainder of the thesis.

Green criminology is the primary discipline that this research will contribute to. This is inherently due to the nature of green criminology, a theoretical perspective that considers acts and omissions that cause harm and victimisation that may result from both legal and illegal acts (Jarrell et al. 2013: 423; South, 2014: 5). Mainstream, orthodox criminological theory is not appropriate to the analysis of environmental harms from UHF processes because criminology is restricted to observing violations of the criminal law. Hydraulic fracturing is a legal production process in the UK and therefore does not fall under the remit of criminology (at least when the research focus is on environmental harms that result from legal production practices[12]).

3.2. **Green Criminology**

3.2.1. Historical Context

It is generally accepted, within the green criminological academic arena (Brisman, 2014; Brisman and South, 2012: 3; Halsey, 2004; Stretesky et al. 2014; Wyatt, 2013), that green criminology originated in 1990 as a result of Michael Lynch's seminal work entitled *The Greening of Criminology: A Perspective for the 1990's* (Lynch, 1990). This was not, however, the first work to establish causal connections between environmental harm and social, economic and political interactions (for examples, see: Commoner, 1977; Enloe, 1975; Johnson, 1973; Schnaiberg, 1980; Stretton, 1976; White Jr, 1967).

However, Lynch's (1990) work called for the academic discipline of criminology to engage with environmental issues, with a specific purpose that would focus on *legal* human acts and omissions that cause harm to the environment. Indeed, it has been recognised within the literature and those studying *green* or *environmental* victimisation, that environmental harms are often legal acts which leave victims of environmental harm unaccounted for, or even 'missing' (Hall, 2013; 2014; Skinnider, 2013). Because green

[12] This is not to say that criminologists should ignore the effects of oil and gas development which may be appropriate for analysing more 'traditional' forms of criminogenic behaviour and correlating this with production. For example, a recent study from Stretesky et al. (2018a) found that onshore oil and gas wells are positively correlated with both violent crime rates and property crime in the UK.

criminology attempts to assess harms that may be of a legal origin, it has been dubbed a strand of radical criminology (Lynch, 1990; see also Lynch and Stretesky, 2007) that is different to orthodox criminology that largely focuses on violations of the criminal law. In the context of this research, then, it must be remembered that hydraulic fracturing is a legal process in the UK and, therefore, green criminology is a fitting lens from which to view any environmental harms that many emanate from such a process.

It can be argued that the emergence of a *green* criminology can be seen as a failure by orthodox criminology, and mainstream criminologists, to approach environmental crimes and harms generally. Prior to Lynch's (1990) work, criminologists had largely ignored harms to the environment simply because they do not always breach the criminal law and are therefore not deemed to be under the remit of criminology (Stretesky et al. 2014).

Despite this, it is irrefutable that certain environmental harms have the same consequences (or even more harmful consequences) than the more mainstream crimes that orthodox criminology is traditionally associated with. For example, a criminologist attempting to explain the behaviour of a person who has committed a murder is exceptionally important in the following treatment to be administered to the criminal and in the prevention of further murders taking place by that individual (and in the understanding of similar murders from other criminals). In this case, it is evidently important to understand the actions of the criminal who has actively broken the criminal law to cause harm. Green criminology however, attempts to explain harms that may not violate criminal law but are actions that similarly can cause harm to humans and even death. For example, the legal transportation of Waste of Electrical and Electronic Equipment (WEEE) from the UK to Ghana and China are legal acts (encompassed by poor or non-existent state regulation) that causes extreme damage to natural environments and severe harm to human health in the form of developmental damage, organ damage, and cancer due to chemical exposure (Gibbs et al. 2011; Huo et al. 2007). Such harms put orthodox criminology in a difficult position, mainly because *legal* victimisations contradict one of the quintessential underlying principles of criminology; the study of violations of the criminal law (Lynch et al. 2015).

A small handful of those in the green criminology sphere have attempted to offer explanations as to why traditional criminology has failed thus far to explain environmental harms and crimes (Halsey, 1997; 2004; Williams, 1998; Stretesky et al. 2014). For example, prior to offering a critique of green criminology, Halsey (2004: 834, emphasis in original) questions orthodox criminology by posing the following question:

> 'Why at a time when most disciplines (e.g. politics, economics, history, cultural studies) have built or extended their oeuvres to include an analysis of environmental problems, has criminology seen fit *not* to do so? Alternatively, why are there so few criminologists writing about environmental harm/crime, as opposed to the multitude prepared to discuss such issues as illicit drug taking, rape, robbery, homicide and other so-called 'orthodox' crimes?'

There are at least four main explanations for why mainstream criminology has failed to appropriately recognise harms to the environment as being criminological. The first is that, quite plainly, studying environmental crimes and environmental victimisations are 'currently an unfashionable area of academic study' (Williams, 1998: 5). The more conventional, orthodox and (what Williams would perhaps call) *fashionable* areas of study within criminology are the sorts of hard crimes that conventional criminology has habitually centred around that Halsey (2004) draws upon (above), such as drug-taking, rape, robbery and homicide. However, the recent boom in green criminological literature that has emerged since the turn of the twenty-first century (and particularly since around 2007), suggests that the study of environmental harms and crimes are becoming more fashionable within criminology. This is witnessed by the increasing number of emerging green criminology groups (International Green Criminology Working Group, 2015; Economic and Social Research Council (ESRC) Green Criminology Research Seminar Series, 2012-2013), journal articles, and textbooks (Beirne, and South, 2007; Brisman and South, 2014; Hall, 2015; Nurse, 2016; Sollund, 2015; South and Brisman, 2013; Walters et al. 2013; White, 2013; 2009; 2008; White and Heckenberg, 2014; White and Leonard, 2013/2014) specifically devoted to green criminology.

Secondly, harms to the environment often do not directly affect humans but instead affect non-human animals (Agnew, 1998; Beirne, 2009; Nurse, 2013; Stretesky et al. 2018b; Wyatt, 2014) and/or ecosystems (Bisschop, 2012; Boekhout van Solinge, 2014). The harms that affect non-human animals and ecosystems are easily deemed as less important than the harms that affect humans. This is often referred to in green criminology as *anthropocentrism,* linked to how humans view their place on earth and, consequently, how we (as a species) treat the earth and the humans, non-humans and ecosystems that share the lands and the oceans. Anthropocentrism will be discussed in more detail under eco-philosophy (in section 3.4.).

Thirdly, some harms have the ability to be easily rectified (for example, some forms of littering or fly-tipping) or regenerated (i.e. replanting tree's or otherwise restoring an ecosystem) and are therefore deemed to be short-term inconveniences, rather than classified as important research areas. However, in the case of illegal logging of old-growth forests for example, tree's that are extracted illegally are often not replanted by the people or corporations who fell them, nor by the governments or local communities who reside in the areas where illegal extraction has taken place resulting in net annual deforestation (Dauvergne and Lister, 2011: 2). Furthermore, trees that are illegally logged in old-growth forests (such as the Amazon or Congo) are often hundreds of years old and are therefore very valuable to the ecosystems of the forest (Boekhout van Solinge, 2014). Consequently, even if trees were replanted, they would not regenerate as quickly as they were deforested and would not be as ecologically valuable. Felling trees also results in carbon sequestration; the release of carbon into the atmosphere that is stored in the tree (Dauvergne and Lister, 2011: 2). Therefore, whilst some green crimes such as illegal logging may be somewhat rectifiable (i.e. by planting new trees), they may still produce ecological degradation and disorganisation.

The final explanation is a political motivation but, nonetheless, is likely to be a contributing factor as to why orthodox criminology has failed to suitably tackle environment harms and crimes. Hayward (2003) recognises that both the number of environmentalists and environmental problems have increased over the previous few decades but there has been a lack of an adjacent increase in effective action to deal with such issues, mainly, as Hayward (2003: 351) puts it, because environmental problems 'tend to be viewed as discrete issues for policy-makers to deal with.' Alongside this, environmental problems are in constant conflict with state governments other policy commitments, which often take precedence over environmental problems, 'particularly when they favour economic growth and development' (Hayward, 2003: 351). As a result, quintessential governmental environmental objectives crumble at the hands of neo-liberal governmental objectives which are more human-centred. Socio-economic objectives trump environmental objectives as strong economic performance significantly influences the ability of the incumbent government to ascertain re-election. This type of cost-benefit analysis (environmental degradation vs economic growth) will always win-over politicians and the public whilst environmental issues remain one of a multiplicity of differing policy areas (Hayward, 2003).

3.2.2. <u>Definitions</u>

Although green criminology has developed to research environmental harms that are not regarded as violations of the criminal law, there are debates over exactly how green criminology should be defined and what the remit of a green criminology should entail (see, for example, Halsey, 2004; Lynch and Stretesky, 2003; South, 1998; 2014). In an ideal world, *environmental* criminology would be a more comprehensive title that would remove any political insinuations of the colour 'green' that are easily miss-associated to green political ideologies which are not the focus of green criminology (Halsey, 2004).

However, environmental criminology is already a well-established strand of traditional criminology that 'is associated with the study of crime patterns as they relate to particular locations' (Brisman and South, 2012: 116; Hall, 2013: 4) an example of which would be the Chicago School which attempted to explain both the 'social and geographical distribution of crime and delinquency' in 1930's Chicago (Newburn, 2013: 190-191). Multiple academics have attempted to suggest other, more relevant titles for what now constitutes 'green criminology' such as Walters (2010: 180) who proposes the term 'eco-crime' and Gibbs et al. (2011) who propose 'conservation criminology.' Despite these efforts, green criminology currently reigns supreme as the chief conceptual umbrella under which a range of different research agendas relating to environmental harm are able to thrive (Hall, 2013).

This research takes a green criminological approach to hydraulic fracturing in the UK, and subsequently uses Stretesky et al.'s (2014: 2) definition of green crimes as 'acts that cause or have the potential to cause significant harm to ecological systems for the purposes of increasing or supporting production.' This definition adequately conceptualises the type of harm that hydraulic fracturing produces because fracking (a) has the potential to cause significant harm to ecological systems and (b) serves the purpose of supporting the production of natural gas for human consumption. The next section (3.3.) will discuss Treadmill of Production in more detail, and how it can be applied to UHF processes.

3.3. **Treadmill of Production Theory**

3.3.1. The Treadmill of Crime

Treadmill of Production theory is an economic change theory developed by Schnaiberg (1980) and has been dubbed the 'single most important sociological concept and theory to have emerged within North American environmental sociology (Buttel, 2004: 323). It has recently been re-applied to green criminological discourse to explain the structural dynamics of modern society that lead to environmental harm and disorganisation (Greife and Stretesky, 2013; Long et al. 2018; 2012; Lynch et al. 2013; Stretesky et al. 2014; 2012).

Schnaiberg's (1980) theory explained increased environmental degradation witnessed in the post-World War II era. Embedded within the structural theory of political economy based on class structure, ToP recognises 'that the nature of capital investment led to higher and higher levels of demand for natural resources for a given level of social welfare (including wages and social expenditure)' (Gould et al. 2004: 297). Although capital investment weakened employment and led to environmental degradation due to the continued increase in production (and thus extraction of natural resources) in the post-World War II era, profits were being generated leading to capital accumulation in western societies. This capital was then re-invested into technological innovation, replacing older labour practices with newer technological processes. These new processes however, were far more energy and chemically intensive requiring more and more natural resources creating greater ecological disorganisation as a result (Gould et al. 2004: 296). The treadmill notion implies that, like a treadmill, capitalism continually increases production in order to strive for increased profit. The treadmill therefore needs to increase in speed just as production needs to increase to keep accumulating capital. The treadmill notion also relates to the ever-increasing environmental degradation necessary from the ever-increasing production of natural resources to generate that capital, known as; *ecological disorganisation*.

The production of natural resources for human use is of central concern to green criminologists because production processes disturb natural ecosystems according to the two laws of thermodynamics. The first law is the *conservation of matter and energy* which states 'matter and energy cannot be created or destroyed, they can only be transformed' (Schnaiberg, 1980: 13). This leads to the second law, *entropy*, which states that 'all energy transformations are degradations, changing energy from more to less organized forms' (Schnaiberg, 1980: 13). When natural resources are extracted for production (and later consumption), those ecosystems take on less organised forms and become disorganised. Stretesky et al. (2014: 20) use the example of burning trees to create heat as an example of how an ecosystem becomes less organised, (or disorganised):

> 'The energy in the tree is transformed into heat and ash and the energy stored in the tree has become reorganized or disorganized in space… (therefore) many green crimes occur as humans interfere with the ecosystems to produce commodities, and in so doing produce ecological disorganization through economic production.'

The increasing production that is required to generate capital and increase profits in advanced capitalist societies results in ecological disorganisation which, according to Schnaiberg (1980: 230, emphasis in original), appears in two different forms; '*increased environmental withdrawals and additions.*'

3.3.2. Ecological Withdrawals

An ecological withdrawal under Treadmill of Production theory occurs when a natural resource is removed from an ecosystem for the purposes of enabling a person or company to withdraw the economic potential of that resource through its production into a commodity. Hydraulic fracturing for natural gas is a perfect example of an ecological withdrawal where gas is released from shale deposits beneath the land and transformed into an energy commodity to be consumed or exported (see Stretesky et al. 2014: 61-63).

Ecological withdrawals contribute to ecological disorganisation by transforming ecosystems from natural resources into commodities. Because of thermodynamics and the law of entropy, these natural resources take on less organised forms through production. Capitalism relies on the continuous expansion of the economy and the ToP helps to support this expansion. However, as Stretesky et al. (2014: 38) note:

> 'In order to continuously expand production, the ToP must also expand its consumption of natural resources in the form of raw material and energy… the extraction processes associated with these ecological withdrawals destroy the functioning of local ecosystems, and can contribute to the expansion of larger ecological problems, which together generate ecological disorganization.'

As ecological disorganisation accumulates alongside production and economic expansion, environmental law becomes quintessential in the protection of the environment. Most environmental laws operate in a sphere outside of traditional law and traditional notions of what it is to be a criminal. The main reasons for this, identified by Mitsilegas et al. (2015) is that there is a lack of judicial experience for cases concerning the environment, caused by highly fragmented legislation as a result of many environmental reforms in the previous twenty years, alongside the difficulties in applying strict liability to environmental cases. As a result of this, in the UK:

> 'The vast majority of environmental offences that are taken to court are dealt with at a low level [almost 90% of prosecutions are dealt with by the Magistrate's Courts] and are punished with relatively small fines [the average fine is from £1,979 to £2,730 which is far lower than the minimum fines generally applied by these Courts: £5,000, which do not appear to be effective sanction when compared with the profits that can be generated from activities that cause environmental damage' (Mitsilegas et al. 2015: 49).

Treadmill of Production theory implies that the explanation for this difference in sentencing between environmental and more *traditional* crimes is that environmental laws are designed to 'reflect economic interests that maintain and promote natural resource withdrawals that facilitate the expansion of the ToP' (Stretesky et al. 2014: 38). For ToP theory, the relationship between corporations (who cause the most severe and most widespread environmental harms through production) and the state, mean that laws are specifically designed to benefit both sides. By designing environmental laws that allow corporations to produce (and subsequently pollute and cause ecological disorganisation), the state in return achieves economic growth and capital for allowing such activities to take place, often referred to as the price for 'social progress' (Gould et al. 2008: 12).

Environmental laws and environmental regulations in western societies allow governments to retain a sense of legitimacy in their central role of protecting the people therein. However, Stretesky et al.

(2014: 40) acknowledge that 'these rules typically favour capitalists' economic interests.' This state of affairs presents the false assumption that if environmental harms and degradation are not defined as criminal under law, then they must not be harmful enough to be worthy of criminal status (Stretesky et al. 2014: 3). Hydraulic fracturing is an example of a legal production process that has been found to cause significant harm to people and natural environments (see, for example, Jackson et al. 2014). The fact the UK government has designed and passed the *Infrastructure Act* 2015 legalising hydraulic fracturing, gives the false assumption that the practice is not harmful. Despite this, UHF is a clear example of both an ecological withdrawal (extracting gas from shale) and an ecological addition (through the intentional and/or unintentional release of environmentally harmful GHG).

3.3.3. <u>Ecological Additions</u>

Ecological withdrawals occur as a result of extracting resources from a natural environment. Ecological additions occur when those resources are transformed through production processes and reorganised into less organised forms through the law of entropy (Schnaiberg, 1980). The most common example of ecological additions are processes that create pollution (for example, by burning fossil fuels which leads to human-induced climatic change). Ecological additions are damaging to the environment but, just the same way that ecological withdrawals are not always condemned under criminal law, 'not all forms of pollution are regulated… and of those releases that are, an even smaller proportion are treated as criminal' (Stretesky et al. 2014: 67).

Treadmill of Production theory would deem environmental law as ineffective in dealing with ecological additions because such pollution is an essential component to production. Because, as previously discussed, laws pertaining to ecological withdrawals and additions are connected with state-corporate economic objectives and relationships, ecological additions are loosely regulated, rather than criminalised like more orthodox forms of crime. This is noted by Wyatt (2013: 62) who acknowledges that 'it is evident in most peoples and most governments approach to the environment as a whole, where for instance, pollution has maximum levels rather than being restricted altogether.' Hydraulic fracturing creates known ecological additions through the release of GHG's (Speight, 2013: 129-130), and through the storage of wastewaters that are either left to sit in evaporation ponds (Vengosh et al. 2014: 8340), pumped deep underground (Vengosh et al. 2014: 8341), or treated (and later released) at specialist wastewater treatment facilities (O'Donnell et al. 2018). The UK government, through the *Infrastructure Act 2015*, have designed maximum levels of pollution, actively permitting a certain level of pollution. As s.44 of the *Infrastructure Act 2015* states:

> 'The ways in which the right of use may be exercised include—
>
> (a) drilling, boring, fracturing or otherwise altering deep-level land;
>
> (b) installing infrastructure in deep-level land;
>
> (c) keeping, using or removing any infrastructure installed in deep-level land;
>
> (d) passing any substance through, or putting any substance into, deep-level land or infrastructure installed in deep-level land;
>
> (e) keeping, using or removing any substance put into deep-level land or into infrastructure installed in deep-level land.'

Environmental laws like these allow pollution to take place for the purposes of supporting production (such as, in this instance, passing any substance through, or keeping any substance in, deep-level land) which are essential in supporting capitalist societies. Because of this, 'environmental laws make a trade-off between public and environmental health, and economic development and expansion' (Stretesky et al. 2014: 72).

The role of corporate and state actors is an essential component of Treadmill of Production theory in analysing why ecological additions are permitted. Corporations tend to act in ways that enhance production processes which cause ecological disorganisation whilst 'the state tends not to act in ways that reduce the negative ecological impacts of corporations and the production of ecological disorganization. In this sense, the state facilitates green harms caused by corporations' (Stretesky et al. 2014: 76).

3.3.4. Ecological Disorganisation

ToP involves the exploitation of natural resources (ecological withdrawals) through production processes which eventually reorganise matter into less organised forms such as pollution (ecological additions). Withdrawals and additions are types of ecological disorganisations that are natural products of the laws of thermodynamics (Schnaiberg, 1980). ToP requires more technologically-intensive modes of production for companies to remain competitive, which offsets traditional human labour costs. As Long et al. (2012: 331) identify:

> 'Capital investment in chemical technology is therefore the critical link between environmentally destructive production methods and increasing natural resource depletion. In short, firms must maximize profit, reduce their work force, and expand production or risk being viewed as an unattractive capital investment in the financial markets. To make a profit and prevail over competitors, companies constantly find technologies that increase production and reduce human labor costs.'

Therefore, to remain competitive in a market, companies must strive for increased production which involves technological advancements that offset labour costs. When the state implements environmental law and regulation (often as a response to pressure from organised groups), companies argue that such regulations will force them to reduce their labour base, reducing contributions to state taxes (Long et al. 2012: 331; Schnaiberg, 1980). Whilst increased production may initially create new employment, companies argue that environmental regulation that limits or reduces production, will harm both workers and the state meaning they (labour and the state) will always be in support of increased production for economic and employment interests. Therefore, this constant increase in production, constantly drives the ToP and ecological disorganisation (Long et al. 2012).

Technological advancement is regularly offered as a way to limit environmental disorganisation by promoting better efficiency in production (Faulkner, 2014: 15-18). Whilst technology is important in limiting the amounts of ecological disorganisation caused by a particular production technique, it is counter-productive under the capitalist system where increased production and increased use of natural resources is paramount. Production must use natural resources and must create pollution because production can never be perfectly efficient (Stretesky et al. 2014: 67). Therefore, 'technological advances that rely on processes that create ecological disorganization tend to decrease the need for labor and therefore increase social disorganization and destroy ecosystems' (Stretesky et al. 2014: 92-93).

Ecological modernisation theorists advocate that technological advancement coupled with environmental regulation is sufficient is limiting the ecological impact of production (Mol and Spaargaren, 2000: 20). Conversely, ToP theorist's advocate that technological advances and regulations are offset by the ever-increasing production demanded by capitalism (Long et al. 2012). Although so-called *green technology* can decrease pollution outputs per unit, it cannot decrease overall pollution when production (and therefore units) are continually being increased by the ToP (Long et al. 2012: 331). Despite this, proponents of the global fracking industry advocate both technological advancement of the process alongside an increase in production as a solution to demands for global energy. As Chris Faulkner (2014: 146) states in his book *The Fracking Truth*:

> 'Technology is only going to make us more energy efficient in the future, and new sources of environmentally friendly energy sources will be discovered and exploited. But hydrocarbons are here to stay. Our infrastructure is built around this resource and we have it in abundance. There is no other choice when it's between continuing to import energy we need versus perfecting the responsible discovery and production of it here at home.'

Although environmental withdrawals and additions are exceptionally important to Treadmill of Production theory, and to the analysis of human-induced environmental harm for the purposes of supporting production, it could be acknowledged that there is a third dynamic that contributes to ecological disorganisation, related but not fully encompassed by ecological withdrawals and additions. Withdrawals refer to obtaining resources for production purposes whilst additions are those excess by-products of transforming those resources into commodities. Those additions include such things as the burning of fossil fuels and the disposal of different wastes. Deville and Harding (1997: 27) acknowledge (in their own way) withdrawals and additions but make an equally important reference to the energy used in the *transformation* of resources into commodities that acts as a third dynamic to the production process. Whilst you could not have additions without such transformation, there is yet more energy and resource used in the actual transformation process that is not fully acknowledged in the ecological additions literature. Similarly, ecological additions are usually exampled by air pollution and the burning of fossil fuels, but there are other additions that are less regularly acknowledged such as non-biodegradable products (i.e. plastics) and the construction of factories, infrastructure, and buildings that are forced upon natural environments in large quantities but do not easily fit within the category of withdrawal, or addition.

3.3.5. Limitations of the Treadmill of Production

Despite the significance of ToP theory to environmental sociology (Buttel, 2004; Foster et al. 2010), there have been several critiques of the theory. Firstly, there have arguably been no real solutions offered to solve the problem of the ToP. The theory suggests that to solve increasing production requires radical structural changes to the global capitalist system which would require a move away from dependence on economic growth, or even a no growth society (York, 2006). Although ToP has been described as a neo-Marxist extension within environmental sociology, developing a specific type of eco-Marxism (Buttel, 2004), unlike traditional Marxism that offers socialism (and eventually communism) as a preferred societal system, ToP does not offer a better solution to capitalism and can therefore be viewed as pessimistic in its solutions to treadmill problems. Despite this, ToP is exceptionally good at illustrating the 'barbaric, unsustainable character of capitalism's relation to humanity and nature' (Foster et al. 2010: 206).

Secondly, there is a difficulty in understanding the treadmill metaphor which can be interpreted in different ways. Whilst the treadmill envisages the *acceleration* of production leading to the accumulation of capital, the treadmill suggests that ecological disorganisation also accelerates as production accelerates. The fact ecological disorganisation is a negative externality of increased production implies that nature itself is being damaged and is hence moving backwards in terms of ecological health (decelerating in health rather than accelerating) (Wright, 2004: 322). Wright (2004: 322) then, prefers the term 'engine of destruction' to better encapsulate the destructive ecological process of the ToP.

Thirdly, ToP theory can be said to be more focused on production and technology as opposed to *accumulation*, a central characteristic of capitalism. Foster et al. (2010: 203) suggest that, as a result of this, 'there is a significant tendency to underestimate the role of accumulation as the "juggernaut" of capital, as Marx termed it, along with the crisis tendencies it generates.' For Foster et al. (2010), it is much more important to see the problems evident under capitalism as problems associated with a treadmill of *accumulation* rather than a treadmill specifically focusing on *production*. Although production and accumulation are related, the 'accumulation dynamic is enforced by the competitive tendencies of the system and is at one with the concentration and centralization of production… rooted in a system of class exploitation' (Foster et al. 2010: 202).

Finally, Foster et al. (2010) acknowledge that ToP theory concentrates more heavily on scale (i.e. the speed of the treadmill) rather than system which detracts knowledge from micro-toxicity which is exceptionally important in environmental degradation linked to production. 'After all, the level of production can remain the same while the level of toxicity goes up, a reality not normally captured by scale or carrying capacity concepts' (Foster et al. 2010: 204). As a result, the complexity of natural systems and human's contradictory, exploitative exchanges with such systems lies outside of the ToP analysis (Foster et al. 2010: 2014).

This links back to environmental ethics and critiques from 'ecosophers' who argue that natural systems are too complex for humans to ever fully understand (Watson, 1983). As is noted in Barry Commoner's four laws of ecology: 'everything is connected to everything else,' 'nature knows best,' 'everything must go somewhere' and 'there is no such thing as a free lunch' (Commoner, 1971). The final two of these laws are of great relevance to Treadmill of Production theory. *Everything must go somewhere* is easily related to ecological additions, and *there is no such thing as a free lunch* relates to the ecological disorganisation that comes with withdrawals and additions (i.e. natural resources do not come for free, they come at the expense of destructed ecological systems).

Despite these criticisms, the treadmill of production theory provides an excellent examination and evaluation of the relationship between the economy and the ecology. It is for this reason that ToP is drawn upon in this thesis. Additionally, the purpose of UHF (to extract energy, a form of ecological withdrawal) and the ensuing ecological additions that have been witnessed from UHF processes in the United States, make ToP a fitting theoretical perspective from which to analyse UHF.

3.4. **Eco-Philosophy**

3.4.1. Introduction

Over the past two decades, Rob White and Mark Halsey have successfully applied eco-philosophy to environmental harms and crimes (Halsey and White, 1998; Halsey, 2005; White, 2008). They were not, however, the first to apply the philosophical principles of anthropocentrism, biocentrism and ecocentrism to environmental problems. These are well-established principles in the environmental philosophy and environmental ethics arenas (for anthropocentrism see: Gagnon Thompson and Burton, 1994; Nash, 1989; for biocentrism see: Sterba, 2011; Watson, 1983; for ecocentrism see: Gagnon Thompson and Burton, 1994; Merchant, 1990). What Halsey and White (1998) do offer though, are three succinct vantage points from which to view environmental harms and crimes, essentially linking eco-philosophy with green criminology.

Each respective eco-philosophy perceives of human-nature interactions in a different way which, as a result, pertains distinctive ways of responding to cases of environmental harms and crimes. This section will explore the three traits of eco-philosophy in more detail, offering critical analysis to each component. Eco-philosophy will also be applied to hydraulic fracturing in the UK relating the importance of its application to this research.

As has been mentioned, green criminology can be viewed as a radical strand of criminology that assesses both environmental *crimes* and environmental *harms* (Lynch, 1990). It is important to distinguish between harms and crimes when discussing eco-philosophy because many of the most serious facets of environmental harm constitute ‘normal social practice’ and are not considered criminal at all (Halsey and White, 1998: 346). It can be argued then, that for environmental harms that are not criminalised, one must question why they are legal if they have the potential to be harmful (the same way that crimes are criminalised, because they are harmful). Anthropocentric, biocentric and ecocentric perspectives will be analysed in the proceeding paragraphs to assess human-nature interactions that constitute both environmental harms and environmental crimes. As White (2008: 11) asserts:

> ‘there exists a considerable disjuncture between what is officially labelled environmentally harmful from the point of view of criminal and civil law, and what can be said to constitute the greatest sources of harm from an ecological perspective.’

Many scholars have criticised corporations as being extremely harmful to the environment (Dauvergne and Lister, 2011; Long et al. 2012; Pearce and Tombs, 2009; Stretesky et al. 2014; White, 2003: 495). However, Halsey and White (1998) note that environmental harms are not solely reducible to corporations and that deeper structural problems within society are equally as harmful *en masse*. People, for example, who consume fossil fuels or fail to recycle recyclable products all contribute to legal environmental harm, which may appear to be invisible. This implies that environmental harm ‘is in fact ubiquitous – a structural or systemic phenomenon – rather than exclusively contained within… corporate giants or certain careless individuals (Halsey and White, 1998: 347).

The universal, pervasive nature, then, of environmental harms that extend from typical human-nature interactions, require a different outlook. Calling upon eco-philosophy enables us to strengthen our understandings of human-nature relationships enabling us to apply such thinking to legal environmental harms. By doing this, we can better understand *how we view* human relationships with nature, conversely with perhaps *how we should view* human relationships with nature in the best interests of humans, non-human species, and the biosphere more holistically.

3.4.2. Anthropocentrism

An anthropocentric outlook on environmental principles would regard humans as the most morally significant species resulting in the manipulation of natural environments for the immediate satisfaction of human wants and needs. Eckersley (1992: 51, in: Halsey and White, 1998: 349), defines anthropocentrism as:

> 'the belief that there is a clear and morally relevant dividing line between humankind and the rest of nature, that humankind is the only or principal source of value and meaning in the world, and that non-human nature is there for no other purpose but to serve humankind'.

This demonstrates that anthropocentrism gives humans a moral superiority over the biosphere and everything contained therein. As a result of this, everything in nature is perceived to be for the exploitation of (and use of) humans, for the purpose of bettering and empowering the human race. Anthropocentrism is similar to (but distinct from), the term *Anthropocene,* which is a term that describes a new geological epoch (following the Holocene), a 'period in which people have a devastating and overwhelming impact on the earth and its systems' (Kotzé, 2014: 121).

Natural gas residing within various underground basins is seen, under anthropocentrism, as a commercial resource that brings several human gains. These include, for example: economic growth, energy security, use of natural gas for businesses and homes, increased jobs resulting from extraction processes, and decreased reliance on imports/increased ability to export natural gas (Faulkner, 2014; Mason et al. 2015). Under an anthropocentric view, the fact that extracting natural gas has the potential to create serious cases of environmental damage and harm is seen as an externality of the process that should not inhibit humans from enjoying the economic and cultural pleasures associated with natural gas. Under anthropocentrism, then, shale gas is deemed worthy of extraction in unrestricted quantities because of these perceived benefits.

There are several criticisms of anthropocentrism however, which must be analysed. Firstly, the very nature of anthropocentrism is to benefit and advance human wants and needs because humans are deemed to be the most superior species. Ironically, this human-centred approach can only work in the short-term as harming the environment is inevitably detrimental to humans in the long-term. Wyatt (2013: 62) critiques the anthropocentric approach by acknowledging that it:

> 'is so focused on short-term gain that the eventual damage to human livelihoods and health caused by overexploitation is not recognised or acknowledged. Human profits and well-being are threatened in direct contradiction to the aim of an anthropocentric approach, yet in not understanding the interconnectedness of people to the environment, destructive behaviours continue unquestioned.'

An obvious example of this would be human-induced climate change. Practices that contribute to climate change such as, driving a car or powering a coal-fired power station, for example, are useful human practices in the short-term, but all such practices contribute to ozone depletion and temperature rises in the long-term (Flannery, 2015). These practices can be seen as *invisible* environmental harms that do not immediately threaten the short-term existence of humans but, collectively, have the potential to cause severe injustice within, and self-annihilation of, humans as a species.

The anthropocentric response to this would be human ingenuity and technological innovation which are seen as the most appropriate way in which to assure the continued exploitation of nature to satisfy global human consumption habits (Halsey and White, 1998). The following two examples demonstrate how technological innovation can help mask environmental harms which are typical anthropocentric approaches to environmental "preservation":

Example One: Coal-fired gas power-stations emit SO^2 (Sulphur Oxide), a known contributor to acid rain that can have severe negative effects on ecosystems including (in particular) freshwater resources such as streams, lakes, and rivers (Oikawa et al. 2003: 67; Srivastava and Jozewicz, 2001: 1676). As a result, power-stations use SO^2 scrubbers as a technique of flue gas desulphurisation, a technique used to neutralise acid rain with an alkaline substance (often seawater) (Oikawa et al. 2003; Srivastava and Jozewicz, 2001; 1679).

Example Two: In 2010, BP's deep-water horizon well exploded releasing unprecedented quantities of crude oil into the Gulf of Mexico. One of the ways in which the spill was contained was by spraying dispersants (in the form of Corexit 9527) from the air, to manipulate the harmful properties of the leaking oil (Kujawinski et al. 2011) (i.e. using chemicals to contain chemicals).

These examples demonstrate ways in which legal environmental harms are dealt with under anthropocentrism. While these preservation acts go some way in limiting environmental harm, they do not prevent environmental harm occurring in the first instance and can therefore be seen as *reactive* approaches to environmental harm rather than *precautionary* approaches. In the case of example two, whilst spraying Corexit 9527 onto deep-water (and Coretix 9500A at the wellhead underwater) was partially successful in limiting some environmental damage (Kujawinski et al. 2011), it was unsuccessful in the clean-up of approximately 200 million gallons of loose oil, approximately 100 million gallons of which still occupied the Gulf of Mexico four months later (Ramseur, 2015: 3). Environmental regulation in the form of minimising such oil spills, or even investing resources into reducing the risks of such oil spills, means that the risk of a repeat disaster 'is never entirely effaced – only postponed' (Halsey, 1997: 220). This outlook shows that anthropocentric responses to environmental harm are not always sufficient in eradicating environmental harms, they are used mainly as a delay tactic.

Under anthropocentrism, environmental activity is only criminalised in criminal law when human actions harm other humans in the immediate short-term. Offenders who commit environmental crimes that violate criminal environmental law are 'real' offenders existing 'inside' the system (Halsey, 2004: 836). Conversely, people operating "outside" of the criminal law, but who still cause environmental harm, are not considered "real" or "worthy" offenders as their actions do not violate the criminal law. As a result, these "untouchable offenders" are legally permitted to cause environmental harm. Halsey (2004: 836) notes that:

> 'what these actors do (and do not do) may be intentional, may be harmful, and may lead to long-term deleterious effects on ecosystems, but so long as such acts occupy a sphere beyond that dealt with by enforcement agencies, they do not, indeed cannot, constitute environmental crime.'

The fact that so many acts are harmful, yet do not constitute environmental crime can be seen as supportive of an anthropocentric outlook. For example, some forms of environmental crime, such as illegal dumping of hazardous waste, are easily criminalised because they are dangerous acts with short-term, immediate risks to humans. The majority of people do not illegally dump hazardous waste, therefore, that act can be easily criminalised. Burning fossil fuels at home or in a car are small acts that collectively produce environmental harm *en masse* (Halsey and White, 1998), however, most people are guilty of committing these harmful acts, and most of the consequences of such acts are only problematic in the longer term. If all acts that cause environmental *harm* were to be criminalised, most people would break the criminal law at some point, which is an unfeasible situation for criminal justice systems. As a result, (under anthropocentrism) only the most harmful acts (that is, harmful to humans) are criminalised, and the more progressive forms of environmental harm (that affect non-humans and the biosphere) are permitted.

3.4.3. Biocentrism

Biocentrism is the polar opposite of anthropocentrism. This perspective insinuates that all species have equal intrinsic value and that human use of the earth's resources must not inhibit the ability of other species to survive. As Halsey and White (1998: 352) put it when explaining the underlying principle of biocentrists within eco-philosophy:

> ‘biocentrists hold that non-human species have intrinsic value, that is, they possess a moral worth and will continue to have moral worth no matter how insignificant human beings conceive their existence or use value to be.’

Both environmental laws and environmental legislation under the biocentric perspective are not focused specifically toward human beings, but towards the equality of all species in general. The rationale behind such a position is that there is ‘no sense in attempting to ascribe economic value to something which has intrinsic value’ (Halsey and White, 1998: 364) because human beings are regarded as merely another species, as opposed to a superior species (as under anthropocentrism).

There are problems, however, with such an egalitarian outlook. Firstly, how are humans expected to treat non-human species equally when we are unable to treat ourselves with a similar equality and fairness? Sterba (2011: 167) explains this analogy by noting that:

> ‘just as we claim that humans are equal, yet justifiably treat them differently, so too we think that we should be able to claim that all species are equal, yet justifiably treat them differently.’

In fact, humans consistently distinguish between *worthy* and *unworthy* victims. Physically larger, charismatic and critically endangered species such as tigers, rhinos and elephants often receive much more (media and popular) attention and *worth* than other physically smaller, less charismatic, endangered species, such as plants and invertebrates who are often perceived as less worthy or even *invisible* (Wyatt, 2013: 59).

Secondly, a universally biocentric outlook could be potentially damaging for humans and non-humans, just the same way that an anthropocentric outlook could be damaging for humans in the long-term. The theory of Darwinian natural selection for example, does not see premature deaths within species (for example, in humans, through environmental harm that leads to death) as a particularly worrying social problem. In fact, Darwinian natural selection would view particular types of social harm ‘as beneficial, to both species in general and the human ‘species’ in particular, insofar as they lead to a significant reduction in population numbers’ (Halsey and White, 1998: 353). It can therefore be argued that as long as population numbers remain stable, death from environmental harms, environmental crime, and environmental disasters can be viewed as beneficial.

Despite the limitations of biocentrism, the theory does have a cemented position within environmental ethics. Humans, or *homo sapiens* (the distinguished ape which we call man) have existed for approximately 100,000 years (Stringer and Andrews, 1988: 1267). This is a comparatively short amount of time when it is realised that the origin of the universe was approximately somewhere between ten and twenty thousand million years ago (Hawking, 1988: 44). As a result, human existence can be viewed as insignificant in the long-term history of planet earth which undoubtedly renders anthropocentric dominance problematic.

There are two ways of interpreting this under eco-philosophy. Firstly, if humans are simply another species existing at one moment in time, humans should not hinder the existence of other species also existing at that moment of time – a biocentric outlook. Secondly, if humans are simply another species existing at one moment in time, humans should exploit the natural environment and natural ecology as human existence is insignificant in planet earth’s history – an anthropocentric outlook. This again leads back to Wyatt’s (2013) argument of what constitutes worth. Anthropocentrism would propose worth in the sense that because humans are morally superior to all other species, they have the highest worth and should use resources in ways that best benefit them. Biocentrism, on the other hand ascribes all species (including humans) with the same moral worth and therefore resources should be utilised in ways that enable all species to facilitate their basic needs (Sterba, 2011).

Critically analysing anthropocentrism and biocentrism has unveiled flaws in both philosophical perspectives in relation to human-nature interactions. The third and final eco-philosophy, ecocentrism, intends to balance the two outlooks by situating itself between the two, essentially in favour of humans, but interacting with the environment in ways that do not limit the continued use of such environments for future generations of humans and non-human species alike.

3.4.4. Ecocentrism

Ecocentrism is neither entirely anthropocentric nor biocentric in nature yet contains aspects of both of these conflicting philosophies. As a result, it could be described as a *hybrid philosophy* simultaneously combining human needs with environmental needs, dissolving ecological problems from the biological to the social (Halsey and White, 1998: 356). According to Merchant (1990: 55)

> 'an ecocentric ethic is grounded in the cosmos. The whole environment, including inanimate elements, rocks, and minerals along with animate plants and animals, is assigned intrinsic value… All things in the cosmos (then) as well as humans have moral considerability.'

An ecocentric outlook, then, recognises that humans have an inimitable ability to produce and consume through the development of structural mechanisms. Similarly, there is a recognition of responsibility that these structural mechanisms do not exceed the ecospheric limits of the planet, a responsibility that encompasses both humans and non-humans (Halsey and White, 1998: 355). Alongside this recognition, there is a realisation that humans need to both utilise non-human nature in order to survive, whilst simultaneously implementing sustainable principles that do not affect the ability of future human generations to also be able to satisfy their basic needs (Halsey and White, 1998: 356). On the other hand, it can be argued that humans do not always need to utilise or manipulate nature in order to survive, an apt example being human consumption of animals for food. Indeed:

> 'We have no nutritional need for animal products. In fact, vegetarians are, on average, healthier than those who eat meat. The overriding interest we have in eating animals is the pleasure we get from the taste of their flesh' (Singer, 2006: 21).

Consuming animals, then, is human luxury rather than a fundamental human necessity imperative to human survival (at least in the modern, western world). Despite this, ecocentrism prides itself on understanding human-nature relationships and grasping the differences between human needs and human desires. The problem in defining human needs and desires however, is open to much debate as the example of the consumption of animals for food reveals. A critique of anthropocentrism was proposed in section 3.4.2. in that humans, by exploiting the environment for its instrumental use value, is damaging for human survival in the long-term (Wyatt, 2013). Ecocentrism advocates a sustainable, grass-roots level approach to the satisfaction of human wants. In terms of human desires, these can only be maintained over the long-term if such desirable activities work *with* non-human nature rather than against it' (Halsey and White, 1998: 356, emphasis in original).

3.5. <u>**Conclusion**</u>

ToP theory and eco-philosophy were chosen as theoretical concepts to integrate into this thesis for two main reasons. Firstly, both are major theories within the discipline of green criminology. As was discussed at the beginning of this chapter, green criminology is the most suitable perspective under which to situate this research because of the legal nature of UHF, where environmental harm is treated as an externality of the process rather than criminalising the acts that lead to environmental harm. ToP theory provides a structural explanation for the emergence of UHF in the UK rooted in notions of political economy. Eco-philosophy compliments ToP theory by scrutinising human interactions with the natural environment and providing three sub-philosophies that explain these interactions in more detail.

Secondly, both theories have obvious uses for examining UHF. ToP theory is directly applicable because UHF, by its very nature, aims to extract shale gas (an ecological withdrawal), which inevitably involves various forms of pollution (ecological additions, see Chapter Two). According to Schnaiberg (1980), these withdrawals and additions contribute to social and ecological disorganisation which are the two seminal research areas of green criminology (social harm and environmental harm). Furthermore, eco-philosophy could be extremely useful in examining decision-making where UHF is concerned and will be used in Chapters Seven (analysis) and Eight (conclusion) to assess decision-making where UHF is concerned. The next chapter, however, will move on to discuss the methodological approach adopted in the research.

Chapter Four: Research Methodology

4.1. **Introduction**

This chapter will outline the methodological approach undertaken in the research. Section 4.2. will begin by outlining the rationale for the study. Section 4.3. will identify the research questions formulated after the completion of the literature review. The research design will be outlined in section 4.4. paying particular attention to the adoption (and modification) of Kvale's (1996) stages of the interview process, and Miles et al.'s (2014) coding strategy. Section 4.5. will discuss the ethical considerations of the research, and section 4.6. will finish by identifying limitations of the research.

4.2. **Rationale**

The objective of the research was to interview a variety of different people who all had distinctive experiences of UHF in the UK. It was thought that doing this would give a rounded and varied perspective of UHF processes at a time when political and public debates were divided on fracking and two sides appeared to forming: those *pro-fracking* (often UK government personnel; fracking companies; some academics; consultants) and those *anti-fracking* (activists; some academics; some local communities).

A further objective was to ask participants questions relating to several different unanswered concerns that emerged from the literature review. These concerns included five *economic questions* (surrounding the extent to which fracking in the UK could impact upon: energy security; the economy; jobs; property values and community financial incentives) and seven *environmental questions* (surrounding the extent to which fracking in the UK could impact upon: water aquifers; water resources; wastewater; chemicals; flaring; well integrity and seismicity). These topics are all highly debated issues which often results in research and debates that reflect the different sides of the fracking debate.

An additional rationale for this research was to collect qualitative data prior to the commencement of UHF operations in the UK. This precautionary approach to understanding environmental harm is undoubtedly more beneficial for the environment in terms of assessing environmental harm before it may materialise. This goes against the grain of much academic research from the *hard sciences* that often quantifies the harms of UHF after they have already occurred (such as studies from: Boothroyd et al. 2016; Davies et al. 2012; Erno and Schmitz, 1996; Green et al. 2012; Ingraffea et al. 2014; Kang et al. 2014; Karion et al. 2013; McKenzie et al. 2014; Osborn et al. 2011; Taylor et al. 2000; Vidic et al. 2013).

Whilst such studies are still undeniably useful in terms of revealing environmental harm (that may have otherwise gone unnoticed, particularly within legal production processes), a precautionary approach to the study of environmental harm may serve a similar purpose (to identify the potential for harm) whilst providing important information that could influence public policy before environmental harm takes place in such a way as to prevent that harm.

Ultimately, the aim of the PhD research was to collect primary data in the form of interviews with a variety of people with differing knowledge and experience of UHF in the UK. This would enable me to delve down into each issue and explore and uncover the central arguments. The literature review would aid in the understanding of UHF on behalf of the researcher before conducting interviews, whilst also being used in the results and analysis to come to a conclusion around each issue. Therefore, the conclusions of this research are a combination of primary data collected from *key-informants* to the UHF industry in the UK, alongside the analysis of a variety of academic and organisational research.

The term ‘key-informant’ has been adopted from Marshall’s (1996) explanation and exploration of ‘the key-informant technique’ in their work within family practice research. According to Marshall (1996: 92), ‘a key informant is an expert source of information (and) the key informant technique is… now being used more widely in… social science investigation.’

The 20 participants interviewed for the research gave excellent responses and most talked in-depth about all of the issues that I asked of them. However, this resulted in such a great quantity of data that, whilst completing the results and analysis of the interviews, it was realised that all 12 questions could not be debated fully due to word count restrictions. As a result of this, I decided to concentrate the results, analysis and conclusions of the research purely on the potential environmental implications of UHF in the UK, omitting results, analysis and conclusions of the five economic questions. However, the economics of UHF are still included throughout the thesis as there is a definite interaction between the economy and ecology where UHF in concerned.

4.3. **Research Questions**

This research could have developed research questions for each of the 12 specific issues that were asked of participants. However, the interview questions were designed to be broad in order to allow each participant to discuss their own experiences and knowledge with regards to each issue. As a result, I felt that two research questions would provide sufficient focus to the research, concentrating on the potential economic and environmental implications of UHF in the UK, respectively. Therefore, the research questions were as follows:

1. What do key-informants understand to be the economic implications of unconventional hydraulic fracturing in the UK?

> 2. What do key-informants understand to be the most salient concerns regarding the potential for environmental harm in the UK?

However (as discussed in section 4.2.), the economic section of the research was eventually omitted which left one remaining central research question:

What do key-informants understand to be the most salient concerns regarding the potential for unconventional hydraulic fracturing to cause environmental harm in the United Kingdom?

With regards to research questions developed for qualitative research, Miles et al. (2014: 25) suggest that:

> 'research questions may be general or particular, descriptive or explanatory. The research questions may precede, follow or happen concurrently with the development of a conceptual framework. They also may be formulated at the outset or later on and may be refined or reformulated during the course of fieldwork.'

This quotation provides a suitable account of the development of research questions during this research. The two original research questions were developed following the literature review, but preceding data collection. They were developed at the outset but reformulated during the analysis of data to leave one distinct research question.

It must be noted here that, whilst interview questions were developed distinctively out of the literature review (a deductive approach), the varying backgrounds, knowledge and experience of different interviewees presented the opportunity to ask other, specialist questions in order to encourage participants to reveal intimate knowledge that was specific to their particular expertise and experience of UHF in the UK (an inductive approach). Therefore, this research is a mixture of induction and deduction. After all:

> 'there is no need for the researcher to feel that a study must be based entirely on one set of principles or another: it is usually more helpful to consider where it is located on an inductive-deductive continuum' (Harding, 2013: 14).

Therefore, the research is located somewhere in the middle of the induction-deduction spectrum, having clearly defined research questions developed out of the literature review, with some elements of induction based on *probing* questions asked during interviews to encourage participants to speak further of their individual experiences. The research, however, is certainly not an example of grounded-theory (Glaser and Strauss, 1967) whereby a researcher 'approaches a subject without pre-determined ideas of what they are looking for' (Harding, 2013: 13).

Whilst I can see the advantages of a grounded-theory approach to the study of UHF in the UK, an issue that is particularly divided between both experts and the general public of the UK (Department for Business Energy and Industry Strategy (DBEIS), 2018: 7), it would have been impossible to entertain such an approach for two reasons. Firstly, UHF has been a commonplace media issue since 2011 where UHF at Preese Hall resulted in a well barrier failure and low-level seismicity (Green et al. 2012) ensuing a government-induced one-year moratorium on UHF awaiting further research and advice on the practice. Therefore, exposure to such media would make it very difficult not to engage in learning about the complexities of the fracking process. Secondly, my research interest in environmental crime (the PhD studentship for which I had applied) made the controversial and complex issues surrounding UHF an interesting issue that I wanted to research further. After all, one of the central reasons as to why researchers engage in research (and often conduct multiple projects into the same issue) can be driven by a personal interest or experience in a particular topic (Bryman, 2012: 88).

4.4. **Research Design**

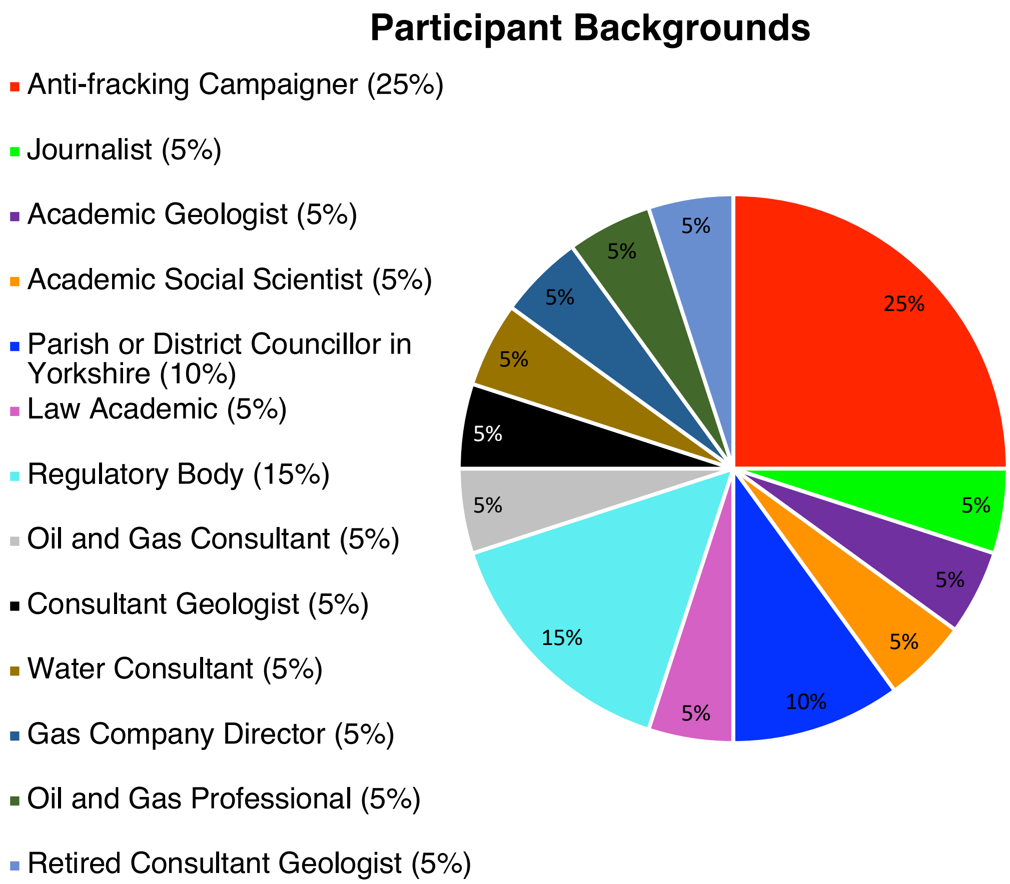
4.4.1. Sampling, LinkedIn and Approaching Prospective Participants

From the outset, the research did not intend to generalise the findings to a general population, as in many social science research studies (Bryman, 2016: 399). Instead, the research intended to collate and bring together the views of different people into one place to identify the main issues and attitudes on a variety of salient issues relating to fracking in the UK. In this respect, the representativeness of the sample and how this may be generalisable to the rest of a population was of little relevance. However, the type of institution, group, company or department the person was part of, was documented and kept in mind when approaching participants in order to make sure the sample was inclusive of a variety of different key-informants. Participant characteristics are identified in the following table:

Participant Number	Gender - Male (M) or Female (F)	Employment Type	Interview Duration (Hours, Minutes and Seconds)
PN01	M	Retired Consultant Geologist	42m 21s
PN02	M	Anti-fracking Campaigner	1hr 5m 21s
PN03	F	Anti-fracking Campaigner	1hr 26m 12s
PN04	F	Journalist	1hr 19m 24s
PN05	M	Academic Geologist	57m 57s
PN06	M	Academic Social Scientist	55m 10s
PN07	F	Parish Councillor	1hr 11m 47s
PN08	F	Law Academic	31m 07s
PN09	M	Regulatory Body	45m 51s
PN10	F	Oil and Gas Consultant	37m 03s
PN11	M	Anti-fracking Campaigner	1hr 11m 26s
PN12	M	Anti-fracking Campaigner	35m 28s
PN13	F	Consultant Geologist	53m 04s
PN14	F	Water Consultant	48m 50s
PN15	M	Gas Company Director	43m 22s
PN16	M	Oil and Gas Professional	39m 49s
PN17	M	Regulatory Body	57m 29s
PN18	M	Regulatory Body	57m 29s
PN19	M	Anti-fracking Campaigner	45m 53s
PN20	M	District Councillor	40m 04s
Total	**7F: 13M**	n/a	**17hr 45m 7s**
Average	**35%F: 65%M**	n/a	**53m 15s**

Table Three: *Participant Characteristics*.

At the end of the first eight interviews, I asked participants whether they supported or opposed the government's decision to undertake fracking in the UK. This was in order to ascertain whether they generally supported or opposed fracking so I could try and ensure an equal representation of views. However, this was often met with hesitation by participants many of whom did not want to be seen as *picking sides*. Therefore, this approach was terminated for the remaining 12 interviews. Instead, when selecting participants, I used my own knowledge and judgement, attempting to select as wide a variety of participants as possible from a mixture of different backgrounds. A visual representation of participant backgrounds can be seen in Figure One:



(Figure One: *Participant Backgrounds*).

When beginning the research, I formulated an approach-list (in a Microsoft Excel Spreadsheet) in order to contact prospective participants. This list cannot be revealed because of participant anonymity as some of the people identified on the list were interviewed. However, to give a flavour as to the methodological approach undertaken, the approach-list identified the following information of potential participants:

- The type of contact (i.e. government, campaigner, consultant etc.)
- The name of the group, institution, or the persons job title
- The name of the person
- Reasoning for their inclusion
- The type of approach made by the researcher (i.e. email, telephone)
- Telephone number
- Email address
- Website (personal and/or professional)
- Social media URL's
- Publications on fracking (if any)
- Any extra important information (relevant previous work history)

This information was all extracted from the public domain, and largely from the website www.linkedin.com. Although the social media site *LinkedIn* cannot guarantee that information displayed on a person's profile is up-to-date (or even truthful), it was extremely useful in gaining an understanding of prospective participants potential knowledge, expertise and background. I decided to utilise LinkedIn because I have worked on LinkedIn in a previous occupation as a recruitment consultant and I have a thorough understanding of how the site works.

Interestingly, during the course of data collection, I noticed that 3 people who took part in interviews for the research changed job role (according to updates on LinkedIn) in the immediate months following participation in an interview for the research. It could be deduced that their participation may have been more likely due to potentially less restrictions from their current employer at the time of interview.

LinkedIn was a useful approach that helped in contacting a number of participants (specifically: PN03; PN09; PN10; PN12; PN13; PN14). However, other participants were contacted through other public domain information (non-LinkedIn), such as personal or professional websites (specifically: PN02; PN04; PN05; PN06; PN08; PN17; PN18). The remaining participants (PN01; PN07; PN11; PN15; PN16; PN19; PN20) were selected through meeting various people at conferences, debates and meetings where UHF was a topic of discussion. As a result, Figure Two (below) provides a visual representation of where researcher-participant contact originated from:

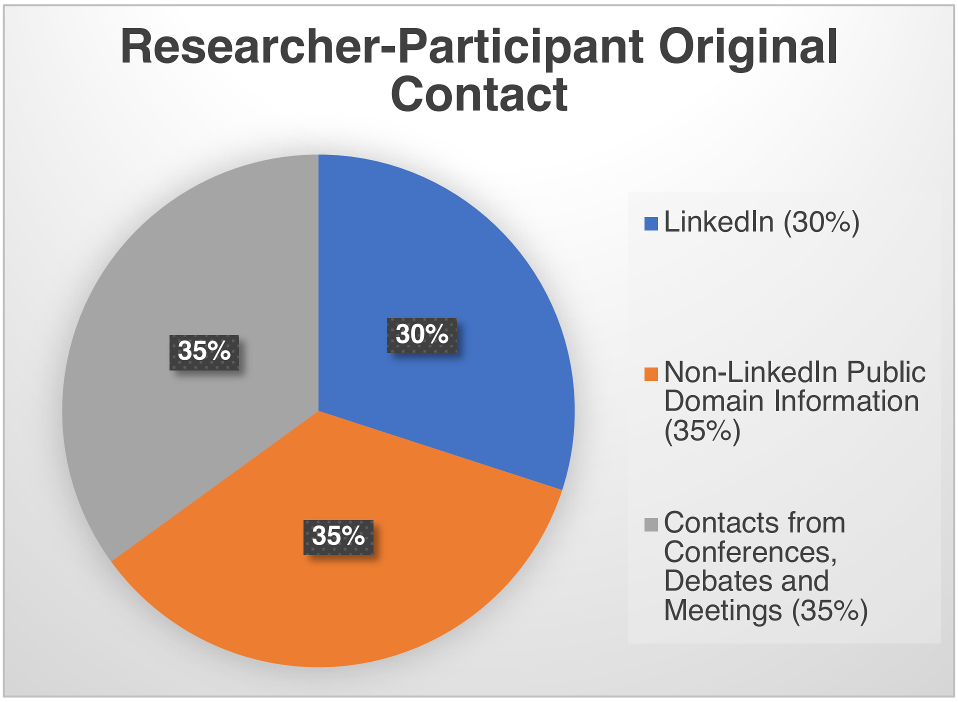


Figure Two: *Researcher-Participant Original Contact*.

Such an approach to sampling and to approaching prospective participants can be seen as a form of *purposive sampling* whereby the researcher (having developed specialist knowledge through a literature review) selects the necessary quantity of differing participant backgrounds to participate in an interview. As Berg (2004: 36) notes, 'when developing a purposive sample, researchers use their special knowledge or expertise about some group to select subjects who represent this population.' The sampling strategy can also be seen as a form of snowball sampling whereby the researcher obtains access to participants through specialist knowledge and experience as fieldwork is underway, rather than before data collection starts. This was particularly apparent when meeting participants (or being recommended to speak with someone via a gate-keeper) at conferences, debates and meetings. Snowball sampling allowed the researcher access to participants who may not have been accessible through public domain information, or through a more fixed sampling technique such as random sampling, often used in quantitative research (Harding, 2013: 17).

Purposive sampling was identified to be the most suitable sampling strategy for the research prior to data collection, largely due to the objective of interviewing a range of people from different backgrounds and with different experiences of UHF in the UK. Such an approach (purposive sampling) is often used within qualitative research, due to the advantage of being able to select desirable participants. As Miles et al. (2014: 31, emphasis in original) denote: 'qualitative samples tend to be *purposive* rather than random. Samples in qualitative studies are usually not wholly pre-specified but can evolve as fieldwork begins.'

The adoption of purposive and snowball sampling was particularly successful in this research because there were some types of participant who did not agree to be interviewed for a variety of different reasons. Ideally, I wanted the perspective and views of those working within a fracking company in the UK to ascertain their industry knowledge and expertise with regards to the potential economic and environmental implications of UHF in the UK. I approached three different fracking companies, all of whom did not agree to an interview. The following quotation, for example, is a reply from Cuadrilla:

> 'Dear Jack,

> Thank you for your interest in Cuadrilla. Because of the high volume of requests from students for input into coursework, with regret, we are unable to engage directly with every request. We would draw your attention to our website where you can find more information on our proposed activities:
> http://www.cuadrillaresources.com/our-sites/locations /
> Good luck with your studies.
> Kind regards
> Enquiries Team'

Whilst INEOS did not reply to an email request, the company Third Energy did (see Appendix Five). Whilst they did essentially agree to participate in the research (although later became unresponsive), the reply was more of a critique of the research project which could be seen as a defence of their operations, rather than a willingness to take part in the research.

Finally, whilst purposive sampling largely worked well as an overall sampling strategy, this method put me in contact with an academic from the hard sciences who agreed to take part in an interview, but the interview had to be terminated after 15 minutes due to the interviewee becoming verbally abusive. I believe that this was the result of the interviewee misunderstanding the nature of social science research. In short, the interviewee was very critical of the interview questions and, as a result, became frustrated with the content of the interview. The interviewee went as far as to insinuate that I did not understand the concept of UHF. This terminated interview was conducted over the telephone and, whilst the Dictaphone was switched off after 15 minutes, the telephone conversation lasted around 90 minutes where I was asked a series of questions about UHF and my PhD project as a whole. After this period, the telephone call ended in a more positive manner with the interviewee apologising for his offensive language and offering his informal help with technicalities of the PhD research. Whilst I have not since contacted the academic, I am satisfied that the conversation ended in a positive way ensuring the potential for a positive future relationship and limiting any psychological frustration and irritation that the interviewee may have felt at the beginning of the interview.

The next section (4.4.2.) considers in more detail the reasoning behind the adoption of Kvale's (1996: 81-105) seven stages of the interview process.

4.4.2. Kvale's (1996) Seven Stages of the Interview Process

Kvale (1996: 81) suggests the adoption of a 'temporal course of a qualitative interview investigation through seven stages: thematising, designing, interviewing, transcribing, analysing, verifying, and reporting.' I adopted Kvale's (1996) approach because of its logical sequence which I believed would help create a clear structure to follow throughout the course of the research. The application of these stages will now be discussed individually, starting with thematising.

4.4.2.1. *Thematising*

Thematising involves thoughtful consideration of the purpose of an investigation and the formulation of research questions to investigate the pre-existing theoretical analysis of the subject area conducted through the literature review (Kvale, 1996: 89). Thoughtful thematising prevents any knock-on effects further in the research process. What is meant by this is, getting things right at the outset (i.e. thinking about; what are the central research questions? What is the purpose of the research?), gives a sense of direction and purpose, preventing misguidedness, lack of clarity and inconsistencies. Thematising has positive knock-on effects for the research process in that it can help to collate more meaningful and purposeful interview questions as well as enabling easier and more consistent analysis of the results of the research. According to Kvale (1996: 88) thematising is used to 'formulate the purpose of an investigation and describe the concept of the topic to be investigated before the interviews start.' In other words, the *why* and *what* should come before the *how* (methods) of a project.

In this regard, the topics of focus for the research came as an absolute result of the literature review whereby the following were deemed as the central concerns of investigation:

> Economic concerns surrounding the extent to which fracking in the UK could impact upon: energy security; the economy; jobs; property values and community financial incentives.
>
> Environmental concerns surrounding the extent to which fracking in the UK could impact upon: water aquifers; water resources; wastewater; chemicals; flaring; well integrity and seismicity.

However, as denoted in section 4.2., the economic concerns were omitted from the research after reconsideration of the PhD word count owing to very large data collection.

4.4.2.2. *Designing*

The second of Kvale's (1996: 88) stages involves 'taking into consideration all seven stages of the investigation, before the interviewing starts.' The best way to explain the research design taking into account all of the research stages is through a combined visual representation of the research in the form of two detailed tables. The first table (Table Four, below) presents the time it took to complete each stage from start to finish. Table Five (see Appendix Six) presents a more thorough explanation of each component:

Task Number	Task	Kvale (1996) Stage	Start	Finish
1	Literature Review	Thematising	September 2015	August 2016
2	Formulating Research Design	Designing	April 2016	April 2016
3	Formulation of Approach list	Designing	May 2016	July 2016
4	Approaching Prospective Participants and Arranging Interviews	Designing	May 2016	August 2017
5	Conducting Interviews	Interviewing	May 2016	September 2017
6	Transcribing Interviews	Transcribing	May 2016	September 2017
7	Coding Interviews	Analysing	May 2016	September 2017
8	Formulating Results	Analysing	November 2016	November 2017
9	Analysing Results	Analysing	November 2017	April 2018
10	Reconfiguration of Literature Review	Analysing and Thematising	April 2018	May 2018
11	Drawing Conclusions	Reporting	April 2018	May 2018

Table Four: *Timeline of Research Tasks*.

It is important to note here that, for the first eight interviews, I asked participants three additional questions at the end of each interview. These three questions were as follows:

1. The UK government believes that shale gas will act as a bridge to a low carbon future. Do you support or reject this statement?
2. Personally, how would you like to see the UK's energy mix?
3. Do you support, or oppose, the government in their commitments to developing the UK's onshore hydrocarbon resources?

The purpose behind these questions was to ascertain, as a whole, the extent to which participants agreed or disagreed with the government's plans to develop shale gas through the technique of UHF. However, I decided to terminate these questions because most of the participants did not agree to answer. I believe that this is a result of them not wanting to be seen as 'taking sides', despite the fact interviews were strictly confidential.

4.4.2.3. *Interviewing*

A detailed account of interview dates, methods and locations can be found in Table Six:

Participant Number	Date of Interview	Face-to-Face (F2F) or Telephone (T)	Interview Location
PN01	27/05/2016	T	University Library
PN02	23/05/2016	F2F	Hired Room at Community Centre
PN03	03/06/2016	T	University Library
PN04	08/06/2016	T	University Library
PN05	21/07/2016	T	University Library
PN06	22/07/2016	T	University Library
PN07	26/07/2016	F2F	Coffee Shop
PN08	15/08/2016	F2F	Staff Office in University Building
PN09	30/09/2016	T	University Library
PN10	13/10/2016	T	University Library
PN11	17/10/2016	F2F	Hired Room in Local Town Council Building
PN12	29/11/2016	F2F	Hired Room in Local Volunteer Centre
PN13	13/01/2017	F2F	Private Room in Business Office
PN14	17/01/2017	T	University Library
PN15	20/01/2017	T	University Library
PN16	02/02/2017	F2F	Booked Seminar Room at University
PN17	23/03/2017	F2F	Meeting Room in Business Office
PN18	23/03/2017	F2F	Meeting Room in Business Office
PN19	13/06/2017	F2F	Meeting Room in Business Office
PN20	04/09/2017	F2F	Coffee Shop
Total	**n/a**	**9T:11F2F**	**n/a**

Table Six: *Interview Dates, Methods and Locations*.

Before each interview began I conducted a verbal briefing with each participant explaining the nature and purpose of the research, and I confirmed that the *type of fracking* we were discussing was UHF, onshore, using high-volume and high-pressure. I also reaffirmed to the participant the usage of a tape recorder and that all responses would remain strictly anonymous and kept strictly confidential (see ethical considerations in section 4.6.). I also finished the briefing by asking each participant if they had any questions prior to the recording of the interview. I used a Dictaphone as a recording device to record interviews and this was placed equal distance between the interviewer and interviewee in order to pick up our voices as clearly as possible. I also used a second Dictaphone in case of any technical difficulties with the original recording device, however, no such difficulties occurred.

I asked 12 pre-determined interview questions to every participant[13]. The order of these questions was very similar in each interview, however, there were some discrepancies in question order between interviews because some of the issues overlapped (for example, chemical usage and wastewater, or water resources and water aquifers). It therefore made sense to ask the most relevant question at the most relevant time which was decided at my discretion during each interview.

Every effort was made when formulating the pre-determined interview questions to avoid questions phrased in a style which may influence the interviewee to respond in a particular manner (see Appendix Seven for list of interview questions). *Leading* or *loaded* questions are often regarded as undesirable because of the influence they may have on the participant to answer in a certain way, a way that may be contrary to their actual beliefs which may

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[13] Besides PN15, a director at an oil and gas company. With this interview I focused heavily on the economics of UHF and the potential effect that shale gas could have on the UK economy. This was because of the occupation of the participant, and the fact that he had revealed to me, prior to the interview, that his knowledge related to shale gas was economically-based (through his workplace) rather than environmentally-based.

jeopardise the validity of the research findings. Participants do, however, invariably have the ability to confute any question which might be leading, but ‘it is the fact that they might feel pushed in a certain direction that is undesirable’ (Bryman, 2016: 254). According to Kvale (1996: 158):

> ‘contrary to popular opinion, leading questions do not always reduce the reliability of interviews but may enhance it; rather than being used too much, deliberately leading questions are today probably applied too little in qualitative research interviews.’

These debates are very relevant to the nature of the interviews that I conducted because the pre-determined questions were designed to be as neutral as possible (i.e. non-leading). However, the semi-structured interview technique adopted enabled me to ask unplanned probing questions which required a degree of judgement. This was an extremely advantageous approach because it allowed me to encourage interviewees to share more information about a particular topic where I felt their experience and knowledge could be useful for the research. This was pivotal due to the varied nature of participants in terms of their work, expertise and background being very diverse. As Harding (2013: 40-41) denotes:

> ‘a qualitative researcher will need to use probes that cannot be planned in advance. A key judgement during an interview is to know when and how to use unplanned questions, comments or sounds in order to elicit further information… Good probing can be the key to carrying out an effective interview.’

4.4.2.4. *Telephone Interviewing*

Telephone interviews were used where it was impractical for me to travel to a particular location to conduct a face-to-face interview, or where the prospective participant agreed to an interview but wanted to take part in a very short time-frame. This happened because of the nature of collecting qualitative research with a variety of different stakeholders who resided in a variety of disperse locations across the UK. As Berg (2004: 93) notes; 'the primary reason that one might conduct a qualitative telephone interview is to reach a sample population that is in geographically diverse locations.'

However, the value of face-to-face interviews was recognised and I tried to use this method as often as possible, always in preference to a telephone interview. As Berg (2004: 93) points out, 'telephone interviews lack face-to-face non-verbal cues that researchers use to pace their interviews and to determine the direction to move in.' Similarly, 'it is not possible to observe body language to see how interviewees respond in a physical sense to questions' (Bryman, 2016: 485). This is particularly important where discomfort or confusion are involved and the interviewer is unable to pick up on these physical cues. However, due to the non-sensitive nature of the subject in question and subsequently, of related interview questions, the ethical need to detect this type of body language was less evident than studies that may involve a degree of psychological harm or distress.

Besides such ethical considerations, there are also practical issues that limit the value of telephone interviews. Participants may be more likely to terminate a phone call if something more important or personal arises, as opposed to a face-to-face interview where the participant is more committing of their time (Bryman, 2016: 485). Thankfully, this did not happen during the course of any telephone interview. However, on one occasion, I did arrange a telephone interview where the prospective participant cancelled two days before we had arranged to conduct the interview over the telephone, giving the following reasoning via email:

> "Hey Jack, I am really sorry to say that I cannot participate in the interview. It has not been approved by my manager (my time is

> extremely limited at the moment and we have to prioritise the really important stuff).”

In this case, although the interview may still have been cancelled if the arrangement had been for a face-to-face interview, the fact we had arranged a telephone interview may have made it easier for the prospective participant to cancel.

The final limitation of the use of telephone interviews arises with clearly picking up the voices of the interviewees over the telephone, coincided with the possibility of a poor telephone connection (Bryman, 2016: 485). This was the case in some interviews where parts of the conversation were not picked up well by the Dictaphone. When conducting telephone interviews from my mobile phone, I placed the device on loudspeaker with the Dictaphone in close proximity. In hindsight, a more successful technique could have been to install call recording software onto the mobile phone and record the interview that way, instead of (or as well as) using a Dictaphone. This could have improved the quality of recordings of telephone interviews.

However, on the whole, the quality of recording from telephone interviews was just as good as face-to-face interviews. Furthermore, some of the face-to-face interviews also experienced some difficulties in recording. For example, the interview with PN07 (conducted in a café) had music playing in the background. Similarly, the academic building where the interview with PN08 was conducted was undergoing construction work, and there was some faint background noise associated with this on the interview recording. Finally, the recording from the interview with PN20 (also in a café) picked up background laughter and voices from other coffee shop users. Whilst these interviews could have resulted in a poor-quality recording, the quality of recording was still very high for the large part, which is probably a reflection of the quality of the Dictaphone and its strategic positioning in close proximity to both interviewer and interviewee.

By the end of the final interview, the researcher felt that participants, despite their different backgrounds, were giving very similar responses to many of the interview questions. It was therefore felt that a point of *saturation* had been reached. As Kvale (1996: 102) notes: 'if… the purpose of the study is to find out attitudes… new interviews might be conducted until the point of saturation, where further interviews yield little new knowledge.' The concept of saturation occurs when the researcher is confident that they have reached the 'point beyond which nothing new or unpredictable would turn up' (Alasuutari, 1995: 59). Therefore, this, coupled with the large volume of data that had been collected from the 20 interviews, felt like the right time to stop data collection, and finish transcribing, coding and analysing the existing data.

4.4.2.5. *Transcribing*

I personally transcribed all 20 interviews for two reasons. Firstly, this was the cheapest method. Secondly (and most importantly), transcribing my own interviews brought me closer to the data (Bryman, 2016). By *closer* to the data, I mean that self-transcription enabled me to recall the interview whilst listening to the voice recorder. This meant that I could type up the interview in a manner which I thought best represented what was said in the interview. Furthermore, self-transcription enabled me to remember who said what and where, which made the process of writing up the results and analysis much easier, in terms of finding quotations.

However, transcribing interviews does come with complications as the process is in itself subjective, whereby the transcriber is interpreting the voice recording in their own way which, if transcribed by another person, may result in a different interpretation and, hence, a different transcription. As Harding (2013: 50) notes, ‘transcribing inevitably involves an element of interpretation; spoken language needs punctuation to be added to it as it is written down and the position of full stops, dashes and so on, reflects the transcriber’s interpretation of what was said.’ Whilst this can be seen to be problematic, self-transcription by the interviewer is much more likely to be an accurate reflection of the interview, more so than a person who was not in attendance at the interview (for example, if the recording is sent to a private company to transcribe).

For the transcribing process I decided to write down text as close as possible to spoken language, including filler words such as: *um* and *er*. Whilst this may have made for more difficult reading, it gave transcripts a much more personal feel, indicating where a participant may have felt confused about a question, or where there was an interaction between interviewer and interviewee that resulted in laughter, for example.

4.4.2.6. *Analysing*

After transcribing interview recordings, I undertook a coding process with each interview transcript. The purpose of this was to condense the vast quantity of written text, identifying what I thought were the most important parts for the research. Whilst this can be seen as a subjective process, coding is extremely important as a component of thematic analysis.

The original plan (when designing the research methodology) was to insert text transcriptions into qualitative data analysis software, such as NVIVO. I experimented with both NVIVO and Microsoft Excel in the early stages of coding in order to deduce which technique I preferred and which would be most suitable for the research. Whilst I saw NVIVO as being advantageous in terms of having all the data in one place, I did not see any technical advantages of using NVIVO over Microsoft Excel. I attended a two-day NVIVO training workshop at the University of Lincoln to learn more about the software and to experiment with example data. I concluded that the software would have been very advantageous for a mixed-method approach (such as amalgamating videos, text, social media or visual data), but I did not think NVIVO would be any quicker, easier, or more important for the data than using Microsoft Excel. The advantage of Microsoft Excel that finalised my decision to use this software over NVIVO, was that the data could be presented on one page in a series of rows and columns, enabling me to visually see all the data for a particular interview, and my own comments. This is not possible on NVIVO software which is much more comparable to a computerised file-system.

With regards to the theoretical side of coding and following an established and recognised process, I decided to mirror the coding procedure identified in Miles et al.'s (2014: 71-85) textbook: *Qualitative Data Analysis*. Here, the authors map out different coding styles that can be applied to various forms of qualitative data (such as differences between factual, emotional or political responses from participants). Miles et al. (2014: 74-81) identify the following forms of coding: descriptive; invivo; process; emotion; values; evaluation; dramaturgical; holistic; provisional; hypothesis; protocol; causation; attribute; magnitude; subcoding; and simultaneous. Out of these 16 different varieties, I decided to adopt just five, as I deemed these the most applicable to the data. The following Table (Table Seven, below) identifies which were used, what their purpose was, and the justification for their use in the research:

Name	**Purpose**	**Justification**
Invivo	'Words or short phrases from the participant's own language… (including) folk or indigenous terms	The diversity of participant characteristics and differences in local

	of a particular culture, subculture, or microculture' (Miles et al. 2014: 74).	dialect enabled invivo codes to be utilised.
Emotion	'This method enables the emotions recalled and/or experienced by the participant… it also provides insight into the participants' perspectives, worldviews, and life conditions' (Miles et al. 2014: 75).	This code was generally only utilised when a participant had a positive or negative opinion about a facet of UHF.
Holistic	'This method applies a single code to a large unit of data in the corpus, rather than line-by-line coding, to capture a sense of the overall contents and the possible categories that may develop' (Miles et al. 2014: 77).	This code was often used due to some participant responses being very long. This code form was applied to quotations of 10 lines or more.
Protocol	'The coding of qualitative data according to a pre-established, recommended, standardised, or prescribed system' (Miles et al. 2014: 78).	This was the most commonly used code because the interview questions were developed from the literature review, and protocol codes were easily developed based on this. Table Eight (below) identifies protocol codes used.

Subcoding	"A second-order tag assigned after a primary code to detail or enrich the entry' (Miles et al. 2014: 80).	This code type was used often in the coding process to add extra detail (usually to a protocol code, but also other code forms). This saved time during the collation of results because many subcodes were the same, or very similar.

Table Seven: *Different Forms of Coding*.

Table Eight (below) shows the abbreviations of the different protocol codes that I used when coding interview transcripts. This made it easier when writing up the results and analysis of the research to collate all separate codes together (for example, all codes related to water aquifers, from all of the different interviews).

Abbreviation of Protocol Code	**Theme Identified from Literature Review**
JOBS	The potential impact, if any, of UHF on: Jobs.
PV	The potential impact, if any, of UHF on: Property Values.
ES	The potential impact, if any, of UHF on: Energy Security.
ECON	The potential impact, if any, of UHF on: The Economy.
CFI	The potential impact, if any, of UHF on: Community Financial Incentives.
WA	The potential impact, if any, of UHF on: Water Aquifers.
SEIS	The potential impact, if any, of UHF on: Seismicity.

CHEM	The potential impact, if any, of UHF on: Chemicals.
WI	The potential impact, if any, of UHF on: Well Integrity.
WW	The potential impact, if any, of UHF on: Wastewater.
WR	The potential impact, if any, of UHF on: Water Resources.
FL	The potential impact, if any, of UHF on: Flaring.
OVN	The participants conception of UHF as an old or new technology. This was used as an introductory question to get the participant thinking and talking about fracking. It was deduced from the literature review, but did not make up part of the analysis which focusses on the environmental aspects of UHF.

Table Eight: *List of Protocol Codes*.

4.4.2.7. *Verifying*

The purpose of verifying is to 'ascertain generalizability, reliability, and validity of the interview findings. Reliability refers to how consistent the results are, and validity means whether an interview study investigates what is intended to be investigated' (Kvale, 1996: 88).

I did not actively engage in the verifying process because I was not attempting to generalise the findings to a certain population. On the contrary, my primary aim was to collate information from a diversity of populations, rather than one specific type of person. Because of the diversity of participant backgrounds, it would have been very difficult to test the reliability and validity of the interview findings to their respective population. As a result, the research can be seen to have followed the other six of Kvale's (1996) stages, rather than all seven (i.e. thematising, designing, interviewing, transcribing, analysing and reporting).

4.4.2.8. *Reporting*

Very simply, reporting of the data took the form of two results chapters (Five and Six) each reflecting similar deductive codes (*water* in Chapter Five, and *other issues* in Chapter Six). This reporting consisted of taking each deductive code in turn and analysing participants interpretations of how UHF (if at all) could potentially lead to environmental harm in that area. The reporting of data in this way was combined with relevant academic and organisational literature in each area in order to give context and meaning to participant responses and to enable evaluation.

The reporting of data can also be seen in Chapter Seven (analysis) where the results were intertwined with the theoretical concepts of ToP and eco-philosophy. Doing this enabled reporting on the conclusions of the research (in Chapter Eight) a simpler process.

4.5. **Ethical Considerations**

4.5.1. Informed Consent

Participants were asked to sign two identical Participant Consent Forms (PCF) prior to taking part in the interview (one for the participant to keep, and one for the researcher to keep, see Appendix Eight). The PCF had two main purposes. Firstly, it was used as an agreement between the two parties to ensure confidentiality through means of identify protection (an agreement that the research project would not in away reveal the participants identity). Fine et al. (2000: 113) note that many informed consent forms are also used to aware the participant of the possibility of harm (for example, psychological or physical) in advance. This notion of harm was not incorporated into the PCF for this research because the subject area, alongside the interview questions, were of a non-personal nature focusing less on the individual’s personal life, but on their knowledge and experience of UHF in the UK. Therefore, there was an exceptionally low risk of psychological or physical harm, particularly when it is realised that participant responses were strictly anonymous and therefore untraceable to each respective participant.

The second purpose of the PCF was to remove any liability from the researcher (and the host institution) by giving control of the research process to the researcher (Fine et al. 2000: 113). The PCF for the research informed participants of a number of the ethical considerations of the research including that:

- Their participation was voluntary and they agreed to take part.
- They were free to withdraw at any time without giving reason and without any negative consequences.
- They were free to decline to answer any question/s.
- Their responses would be kept strictly confidential.
- Their responses were anonymous and they gave permission to the research team to have access to those anonymised responses.
- Anonymised responses and data could be used in future research.

Nineteen of twenty participants signed PCFs and, as a result, there were no problems with regards to ethical considerations because of this. One participant (PN06) did not sign a PCF despite several attempts from the researcher to obtain one. However, prior to conducting the telephone interview with PN06, the researcher talked through the ethical considerations of the research outlined in the PCF and Participant Information Sheet (see Appendix Nine) (these were also emailed to the participant). PN06 gave verbal consent to the researcher prior to the commencement of the interview. Although PN06 said that he did not require confidentiality, the researcher informed PN06 that this would still happen in-line with the methodological approach that was adopted for the research prior to the commencement of interviews.

4.5.2. Confidentiality

Confidentiality was retained at all times throughout the research and no names were used at any point when writing up. Participants were made aware of this verbally prior to the interview, as well as through the Participant Information Sheet and PCF. Participants were also made aware, verbally, that every effort would be made to omit any passages that may link what the participant said to their identity. This was done through the transcribing of interviews by the researcher[14].

4.6. **Limitations**

One of the main critiques of this research (and qualitative research more generally), is that it could be seen as subjective. As the researcher, I decided what the important themes were from the literature review, I designed the research methodology and selectively chose participants through purposive and snowball sampling. I conducted, transcribed, coded and interpreted interviews and drew out conclusions. I also decided which theoretical concepts to apply and what the recommendations of the research should be.

However, this research does not claim to be a perfect example of qualitative research (if such a thing exists). Nonetheless, this does not mean that such an exploration was futile. On the contrary, the diversity of participant characteristics who partook in the research

[14] Many interviews show instances of this where the researcher has omitted a word, name or phrase from the transcription in replace of the phrase: (omitted: confidentiality), to demonstrate that a certain passage has been removed from the text for ethical reasons.

gave a unique insight into the views of key-informants, those knowledgeable of UHF processes in the UK, a methodology that (to the best of my knowledge) has not be undertaken before in such a context. Therefore, this is an exclusive piece of research that has recorded and interpreted a breadth of views and, whilst the findings and conclusions may not be generalisable to all UHF operations, in all places, at all times, it does give an excellent account of key-informant views of UHF in the UK between May 2016 and September 2017 (the duration of data collection).

Qualitative research is often criticised for being notoriously difficult to replicate (Bryman, 2012: 405; Myers, 2000), and this research is a further example of that. According to Bryman (2012: 405):

> 'precisely because it is unstructured and often reliant upon the qualitative researcher's ingenuity, it is almost impossible to conduct a true replication, since there are hardly any standard procedures to be followed.'

Despite this, the research methodology did follow two loose structures which would aid in the ability to replicate the study. These were Kvale's (1996) seven stages of the interview process, and Miles et al.'s (2014) coding process.

A second limitation can be found in the sample. Whilst a good deal of diversity was achieved in terms of interviewing key-informants from a range of diverse backgrounds, it would have been preferable to have input from fracking companies (see section 4.4.1. for details on why this was not possible). Furthermore, although three regulators were interviewed, it would have been valuable to have attained insight from a great number of this type of participant. This is because regulators, at the time, were one of the only participant types (alongside fracking companies, consultants, and those involved with planning) to be actively working on fracking in a practical sense (rather than, for example, in a campaign capacity or more theoretically through academic research).

Additionally, it would have been beneficial for the research to interview key-informants directly involved with planning, particularly at the local authority level. This is because, on top of the HSE and EA, the LPA is the third and final regulator involved with decision-making where fracking planning applications are concerned (and, therefore, those involved in the planning processes were likely to have a great deal of knowledge of fracking at the local level). Despite this, at least six participants are likely to have been involved with planning concerns in some way, through their occupation. These included the Parish Councillor and District Councillor (PN07, PN20), the three regulators (PN09, PN17, PN18) and the journalist (PN04). In reality, all 20 participants could have been involved in planning in one way or another (such as through: attendance at meetings; giving evidence; or, writing letters of commendation or objection). In retrospect, I would have ascertained each participants involvement (if any) in planning processes during each interview in order to obtain this information.

Finally, as was noted in section 1.4., the questions asked of participants in interviews regarding the potential economic implications of fracking in the UK (on the economy, energy security, property values, and community financial incentives) could not be included in the results, analysis and conclusions of the research due to the word count restrictions of the thesis. Again, in retrospect, I should have considered the word count prior to designing my research methodology, at which point I may have omitted the economic questions from the interview structure. However, I do not believe that discussing such issues with participants was futile because it aided in my own knowledge, as the interviewer and researcher, which undoubtedly gave me a greater understanding of the economics of fracking which can only be a positive for the thesis.

4.7. **Conclusion**

This chapter has outlined the methodological approach that was adopted in the research by discussing how Kvale's (1996) and Miles et al.'s (2014) methods were embraced and moulded in order to best address the central research question. Additionally, the chapter has presented details of participant backgrounds and information regarding the details of interviews, how the research was designed, and how participants were approached. Furthermore, section 4.5. discussed the central ethical considerations of confidentiality and informed consent, and limitations to the research were highlighted (in section 4.6.).

The following chapter presents the results for the first main body of interview data concerning water. This combines participant responses to the deductive questions asked of them concerning the potential for UHF processes in the UK to create environmental harm in respect of water aquifers, water resources and the management of wastewaters. Chapter Six will move on to discuss the other deductive issues considered in interviews which encompass; seismicity, chemical usage, well integrity and flaring. Chapter Seven will present the analysis of this interview data by incorporating ToP and eco-philosophy, and Chapter Eight will present the conclusions of the research.

Chapter Five: Results (Water)

5.1. **Introduction**

Chapter's Five and Six are both results chapters focussing on different aspects of UHF in relation to their potential impact on the environment. Chapter Five will discuss the three deductive questions asked of participants in interviews that specifically concern water. More specifically, section 5.2. will consider water aquifers, section 5.3. water resources, and section 5.4. wastewater disposal. In contrast, Chapter Six will deliberate the four remaining *other* sections (seismicity, chemicals, well integrity and flaring). The reason for this format was to present the results in an easily digestible format with clear, succinct sections, as opposed to one complex and lengthy chapter. Consequently, the results in the following two chapters will follow the subsequent format:

Chapter Five:	Deductive Category One: Water Aquifers
	Deductive Category Two: Water Resources
	Deductive Category Three: Wastewater Disposal
Chapter Six:	Deductive Category Four: Seismicity
	Deductive Category Five: Chemicals
	Deductive Category Six: Well Integrity
	Deductive Category Seven: Flaring

5.2. **Deductive Category One: Water Aquifers**

5.2.1. Introduction

The results for water aquifers have been split into two main sections based on the type of responses given by participants with regards to the question asked of them regarding water aquifers (see interview questions in Appendix Seven). Firstly, section 5.2.2. will discuss participant responses that have been categorised as representing the view that fracking will have no effect on water aquifers (focussing on the casing of wells to prevent contamination, alongside the potential for upwards vertical migration of substances and other geological matter). Secondly, section 5.2.3. will consider responses aligned with the view that fracking will have a negative effect on water aquifers (focussing on the potential for surface spills and the impact of well integrity issues). The first section however, will discuss participant views that fracking will have no effect on water aquifers.

5.2.2. Fracking Will Have No Effect on Water Aquifers

Firstly, it is important to briefly define what is meant by the term *water aquifer* and other corresponding terms. It is also important to understand the importance of water aquifers to humans in order to ascertain their significance. According to the BGS (2017a), a water aquifer is:

> 'a rock formation that is sufficiently porous and permeable to yield a significant quantity of water to a borehole, well or spring. The aquifer may be unconfined beneath a standing water table, or confined by an impermeable or weakly permeable horizon.'

Whilst the term *water aquifer,* then, clearly concerns a rock formation that yields significant quantities of water (whether this be confined or unconfined), the term water aquifer is often used interchangeably with the term *groundwater* which is defined by the Ground Water Foundation (2017) as: 'the water found underground in the cracks and spaces in soil, sand and rock. It is stored in and moves slowly through geologic formations of soil, sand and rocks called aquifers.' Therefore, the term *groundwater* refers specifically to the water found within a water aquifer rock formation. Because these terms are so similar, and essentially refer to water found within geological formations underground (and distinct from surface water) the thesis will use the terms interchangeably. Another reason for this is because participants also used both terms interchangeably.

Groundwater is essential to the UK because it provides a safe, fresh source of drinking-water. Drinking-water is also acquired from reservoirs and rivers, and the use of groundwater for drinking-water varies around the UK depending on which water sources are used for abstraction by water companies. For example, Yorkshire Water use groundwater for 22% of the drinking-water supply (Yorkshire Water, 2017) whereas Southern Water use groundwater to supply around 70% of drinking-water (Southern Water, no date). In order to protect such a vital source of drinking-water, a fracking company will case a well using an MBS to prevent substances from leaking into water-bearing rock formations.

5.2.2.1. *Casing Wells to Prevent Contamination of Water Aquifers*

The following two quotations refer specifically to responses that the researcher believes represent the idea that the participant considered fracking will have no effect on water aquifers, referring specifically to the ideas of sealing and casing wells to protect water aquifers from contamination. The first quotation comes from PN11:

PN11: *"it is unlikely that the actual drilling, um, will cause serious damage to the aquifers because the actual drilling is no vast shaft that goes down, it's a relatively narrow pipe, er, and it will have to be sealed."*

Here, PN11 suggests that it is unlikely that drilling will cause serious damage to water aquifers because the pipe that goes down is relatively narrow and the well will have to be sealed. The idea of sealing the well, and that such sealing will prevent fluids, minerals and chemicals from escaping into water aquifers is also suggested by PN18:

PN18: *"shallower rock formations nearer the surface are where you are most likely to get the water bearing rocks and there will be at least three casings and cement so you have got multiple barriers, um, at that sort of, shallower depth anyway. So, they always make sure they are putting those in when they are going through the water bearing rocks."*

PN18 explains that there will be at least three casings and cement which provide multiple barriers. Such an MBS does not continue all the way down the well but does protect the well at the shallower depths where water-bearing rocks are found, and when the operator is accessing a shale formation through water-bearing rock formations (see Appendix Three).

Casing a well is pivotal to the protection of water aquifers from immediate contact with substances that are used in hydraulic fracturing operations (such as water, sand, or chemicals) and from geological substances that are found within produced water, originating from deep underground where hydraulic fracturing takes place (these could include bacteria's, radon, Volatile Organic Compounds (VOC's) and NORM's depending on the geological make-up of each individual location). The importance of casing a well to ensure well integrity and to prevent any subsequent water aquifer contamination is affirmed by the UK government, industry bodies (RSRAE 2012: 4) and fracking companies alike (IGAS, 2017b). To ensure well integrity, well casing designs are submitted to, and reviewed by, the independent well examiner (the HSE) who inspect, scrutinise and monitor wells against industry standards (HSE, no date:b).

However, despite such good-practice techniques in the UK, UHF is by no means a perfect technique. Well integrity has been found to have been compromised in many wells in the United States for a variety of different reasons, leading to well leakage (Jackson et al.

2014). One reason can be bacteria (from wastewater) corroding well casings (RSRAE, 2012: 21), another is simply well operations and the passage of time (Jackson et al. 2014: 337). Although well integrity will be discussed in more detail later in Chapter Six, it must be borne in mind that a lack of well integrity can lead to the contamination of water aquifers, despite participant revelations that well casings provide a seal for preventing contamination to water aquifers.

The next section looks at the upwards vertical migration of fluids from shale formations into water aquifers as a potential reason for environmental contamination. This is placed within this section (fracking will have no effect on water aquifers) because most participants were of the view that the act of hydraulic fracturing does not present a pathway for substances to migrate upwards into water aquifers, thereby having no effect upon them.

5.2.2.2. *Upwards Vertical Migration*

Some UK anti-fracking campaign groups have released media suggesting that UHF can cause induced fractures to propagate vertically upwards providing a pathway for dangerous fluids to contaminate water aquifers (for example: Fracking Free Ireland, no date; Frack Free Bolsover, 2017; see Appendix Ten and Appendix Eleven). Whilst, theoretically, 'any well drilled into the earth creates a potential pathway for liquids and gases trapped underground to reach the surface' (Jackson et al. 2014: 337), most participants who spoke of upwards vertical migration agreed that this would not have an effect on water aquifers.

This complements academic research that suggests the likelihood of induced fractures leading to the vertical migration of substances into water aquifers is very unlikely[15] (Flewelling et al. 2013; Jackson et al. 2014; Stuart, 2012: 12). The first participant to suggest this was PN01, which can be seen in the following quotation:

PN01: *"Well following on from the answer I've just given you to the first part I don't think it will get anywhere near the um the groundwater so it will have nil effect."*

With reference to the terminology "I don't think it will get anywhere near", PN01 is referring specifically to the act of hydraulic fracturing, that is, intentionally causing fissures in shale rock to release the hydrocarbons trapped within. Whilst PN01 clearly understands that fracking will cause fractures in shale rock, he is clear that such fractures will not "get anywhere near" (in other words, will not migrate upwards towards) groundwater residing within water aquifers. Going further than this, PN13 describes the prospect of upward migration into aquifers as "ludicrous":

PN13: *"The prospect of fractures propagating thousands of metres upwards into an aquifer are ludicrous. The likelihood is that this will be at least a thousand metres below an aquifer."*

Importantly, PN13 gives a reason as to why she believes vertical migration to be "ludicrous"; because aquifers exist thousands of metres above hydraulic fracturing target locations (shale formations). This is important because the UK has very deep shale reservoirs at around 1-3 kilometres below the earth's surface (Stuart, no date), meaning that there is a great distance between where hydraulic

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[15] There are few exceptions. For example, Myers (2012) suggests that vertical migration of fluids from fractures to groundwater in the United States could take less then 10 years. Although Myers (2012: 872) suggests that such transport could require tens of thousands of years, 'fracking the shale could reduce that transport time to tens or hundreds of years.'

fracturing is taking place, and where water aquifers exist (up to 200 metres below the earth's surface; see Younger, 2016: 6).

In comparison, the US has places where shale formations are very shallow and, as a result, there is less separation between target formations and water-bearing rock formations. This has resulted in water aquifer contamination, for example, in Pavillion, Wyoming, where hydraulic fracturing occurred as shallowly as 322 metres with local drinking-water wells situated as deep as 244 metres (Jackson, 2014: 342). As a result, the carcinogen Benzene was found to exist in drinking-water wells in Pavillion at 50 times safe levels for groundwater (DiGiulio et al. 2011; Jackson et al. 2014). Whilst lax State and Federal level legislation has been blamed for instances of groundwater contamination in the United States (Jackson et al. 2014: 342), the UK government has placed a restriction on fracking taking place at less than 1,000 metres in s.50 of the *Infrastructure Act 2015,* as well as prohibiting hydraulic fracturing from taking place within protected groundwater source areas. This will ensure that UHF does not take place at the incredibly shallow levels that occurred in places like Pavillion, Wyoming, instead ensuring a great distance between water aquifers and deep hydraulic fracturing locations.

PN05, an academic geologist, also stated that the potential for hydraulic fracturing to cause a pathway into an aquifer is "negligible":

PN05: *"normally shale would be deeper than that at 3 kilometres on average so the fracture, the actual hydraulic fracturing process itself, um, research (omitted – confidentiality) indicate that it is incredibly unlikely that, um, a less than 1% chance of any fractures propagating vertically more than 350 metres and the highest recorded based on US data was around 600 metres. So, if you're 3 kilometres down and your aquifers are 100 metres below the ground or 200 metres below the ground or something like that then the chance of hydraulic fracturing causing a pathway by which fluids can flow from the* *fracking target interval through the aquifer into the aquifer is negligible. Um, so fracking itself I would not expect to be a problem in terms of the literal hydraulic fracturing process."*

Here, PN05 confirms that fracking in the UK will take place in shale that exists at depths of 3 kilometres on average, with water aquifers existing at 100 or 200 metres below surface level. He cites research that suggests there is "a less than 1% chance of any fractures propagating vertically more than 350 metres and the highest recorded based on US data around 600 metres". This means that the distance between shale formations and water aquifers is far greater than the highest recorded vertical fractures documented in the United States. This is confirmed by an influential academic research paper entitled *Hydraulic fractures: How far can they go?* which states that:

> 'Natural hydraulic fracture pipes have the potential to propagate upwards further than stimulated ones. The maximum upward propagation recorded for a stimulated hydraulic fracture to date is ~588m in the Barnett shale in the USA. Based upon the data presented here the probability that stimulated hydraulic fractures extend vertically beyond 350m is ~1%' (Davies et al. 2012: 5-6)[16].

The only serious risk of groundwater contamination comes from the reactivation of a natural geological fault line which may provide a pathway for fluids to migrate and intersect water aquifers, however, this is considered to be a low risk:

> 'The potential for upward fluid migration is considered low. In the worst case, fluid could migrate along the fault plane, but this would be limited due to the presence of impermeable formations above the Bowland shale' (Green et al. 2012: 2).

[16] Other research comes to similar conclusions, that is, that man-made hydraulic fractures do not propagate more than around 600 metres (Flewelling et al. 2013; Jackson et al. 2014: 341; RSRAE, 2012: 4).

Therefore, PN05 is essentially conveying that, whilst a fault line may provide a pathway for fluids, the impermeable nature of several formations that exist above deep UHF target locations means that fluids are unable to flow through such a formation because of such impermeable properties (i.e. fluids do not flow well through impermeable formations).

Similarly, PN14, a Water Consultant, provided the same response as PN05 (above) suggesting that there is a great distance between the location of water aquifers (200 metres below surface) and drilling depth (at 3 kilometres):

PN14: *"there was a lot of concern about fracture migration going upwards into aquifers but we looked at it quite in depth and actually it's because of the depth of where the aquifers are, they are more like 200 metres from the surface and they will be drilling 3 kilometres down. Um, and we can monitor the fracture heights, I've seen the technology and it is very accurate and you can see how, when you put it into scale how far away it is it is just not possible for it to reach the aquifer if you have got overlying geology to protect it. And it would be permitted so the EA would look at your fracture plan and say, oh there's a risk that that fracture might propagate so they do a proper hydro-geological assessment on it."*

There are two other important points that PN14 recognises which are concerned with how the overlying geology protects upwards fluid migration and how operators must submit fracture plans as part of a hydro-geological assessment.

Firstly, then, the geology that exits above hydraulic fracturing target locations contains sufficient pressure to prevent induced fractures extending vertically at great lengths. This geological pressure is one of the reasons why shale rock has to be hydraulically fractured in the first-place (in order to release trapped hydrocarbons). Because shale rock has low permeability (substances do not flow well through the rock), shale has to be fractured to release its contents. Because of the pressure of the overlying strata above, fractures are continually being forced to close (this is why sand is used in fracfluid as a proppant in order to keep induced fractures open for as long as possible, to increase the flow rate and recovery potential of the well). This theme is noted by Fisher and Warpinski (2012: 16) in their journal article on hydraulic fracture height growth:

> ‘Fracture physics, formation mechanical properties, the layered depositional environment, and other factors all conspire to limit hydraulic-fracture-height growth, causing the fracture to remain in the nearby vicinity of the targeted reservoirs. This certainly is a positive feature of hydraulic fracturing and allows many otherwise non-commercial-quality reservoirs to produce hydrocarbons commercially and safely.’

Secondly, PN14 recognises the regulatory significance of conducting a fracture plan. According to the DECC (2015: 44), fracking companies are required to achieve approval from the Oil and Gas Authority (the Licensing Regulator) of their hydraulic fracturing plan for monitoring seismic activity which includes four main actions:

- ‘Operators must establish arrangements to control seismicity and provide a detailed plan for monitoring hydraulic fracturing operations.
- Before granting consent for shale gas operations that include hydraulic fracturing, OGA will require that a fracturing plan be submitted for consideration. OGA will expect operators to demonstrate a full understanding of the risks of hydraulic fracturing.
- Operators will need to evaluate the historical and background seismicity and the in-situ stress regime, and delineate faults in the area of the proposed well to identify the risk of activating any fault by hydraulic fracturing.

- The fracturing plan should also include appropriate plans to monitor seismicity before, during and after the well operations.’

Such a requirement of operators to collect data about the underlying geology not only satisfies the requirements of the OGA, but also provides ‘the EA with information about the techniques being deployed to monitor fracture height growth and fracture geometry’ which assures ‘groundwater will be protected and that no fractures will extend beyond the permitted boundary’ (Third Energy, 2017: 3).

Although many participants expressed that upwards fracture migration would not have an effect on water aquifers, many participants did have other concerns regarding the potential of fracking processes to contaminate water aquifers.

5.2.3. Fracking Will Have a Negative Effect on Water Aquifers

The main reasons given by participants regarding the belief that UHF will have a negative effect on water aquifers in the UK were due to surface spills and well integrity failures which will be discussed in more depth in this section.

5.2.3.1. *Surface Spills*

PN04 was very concerned with the potential impact that surface spills could have on water aquifers and alluded to this possibility several times during the course of the interview which can be seen by the quotations in this section.

The first quotation starts with a direct response to the question posed by the researcher implying that there is conflicting research on evidence relating to the impact of fracking on water quality[17]:

PN04*: "as you quite rightly pointed out there's conflicting evidence about the impact on water quality. In the United States, there's some evidence but the evidence is difficult to pin down because they haven't done any baseline monitoring. Baseline monitoring is going to be carried out in the UK although there are question marks by some people whether how useful it will be. Um (short pause), I think (short pause) I think potentially there is a problem despite the difference in the, um, fracturing zone from the aquifer. Um, I think one of the biggest concerns that people should have is concerns about surface spills actually."*

PN04 implies that a lack of baseline monitoring in the United States has made it difficult to pin down exactly whether fracking has contaminated water in the United States[18]. However, she goes on to suggest that baseline monitoring will be a requirement in the UK. Furthermore, PN04 notes the physical distance between fracturing zones and water aquifers (see section 5.2.2.2.) which presents a "potential problem" but that "one of the biggest concerns that people should have is concerns about surface spills". Surface spills may take the form of spills on fracking sites themselves (Wiseman, 2012: 365) or through the transportation of fracking fluids and materials to and from fracking sites (Wiseman, 2012: 366). The reality of the potential for surface spills emerges when it is realised how many

[17] Academic research exists that suggests fracking processes have a negative impact on water quality (Ramudo and Murphy, 2010: 14-19; Sovacool, 2014: 263). Academic research also exists that suggests fracking itself has no impact on water quality (Wythe, 2013: 17).
[18] This is also likely due to the fact that, prior to 2015, UHF in the United States was exempt from the *Safe Water Drinking Act 1974* which made it very difficult to properly examine the effects (if any) that fracking had on water quality prior to 2015 (Kargbo, et al. 2010: 5679; Sovacool, 2014: 257; Tiemann and Vann, 2015: 38).

truck movements are required to service UHF wells which will be discussed in depth in Chapter Six (section 6.3.3.2.)[19].

The spilling of wastewaters, fracfluid or chemicals (in concentrated form of otherwise) on-site or via transportation incidents clearly presents an opportunity for substances to seep into the earth which could contaminate the natural environment (and water aquifers). PN04 goes into more detail with regards to surface spills in the following quotation:

PN04: *"who takes responsibility for what, um, and where that stops so you know you have, you contract out every single job pretty much on that well pad, um, all the transport is contracted out, um, all the drivers will be contracted for a contract lorry company. Um, and I suspect that the risks are more difficult to quantify of what happens below ground but above ground we know what happens when transport companies cut costs, for example, and this came up in the Cuadrilla enquiry recently because one of the sites at Roseacre Wood was using very narrow roads with, um, you know problems of quite difficult corners, embankments and all that sort of thing and the big concern was that one of these lorries carrying waste, um, was going to overturn and although they say the waste is carried in double skinned tankers, um, there were concerns that a tanker would overflow, the double skin would be damaged and there would be surface spills that could well contaminate aquifers."*

In this quotation, PN04 brings to the fore two important points. Firstly, there are risks when an operator sub-contracts out work, particularly in the form of transport. This could potentially lead to the avoidance

[19] The number of truck movements will ultimately be determined by each individual wellsite, which will vary from site to site largely depending upon the operator and the underlying geology. Although estimations vary, Stephenson (2015: 104-105) notes that 'between 7,000 and 10,000 single truck journeys have been estimated per well pad through the period of construction and fracking.'

of guilt, or a lack of knowledge of fracking and how a fracking site operates (and associated risks), for example. Secondly, PN04 acknowledges that the risks are more difficult to quantify below ground, as opposed to above ground. Although baseline monitoring is a technique used to attempt to quantify, for example, levels of methane in groundwater, it can be exceptionally difficult to remedy the environmental contamination that occurs as a result of groundwater contamination (Dutzik et al. 2013: 10), and it can be difficult to trace where contaminants go once they have dispersed underground (Bergmann et al. 2014: 9).

As well as transportation impacts, above-ground impacts of fracking processes could include impacts on: wildlife, noise, odours and visual impacts (Hammond et al. 2015) as well air pollution emissions from gathering infrastructure (drilling rigs, compressors, pumps, transport equipment) and increased traffic and strains on public resources (Zoback et al. 2010: 12-13).

The final quotation provided by PN04 concerning the potential negative impact of UHF on water aquifers in the UK, is associated with who is responsible for funding the clean-up and restoration of a water aquifer that has been contaminated as a result of UHF activities. Although this topic will be addressed in Chapter Six (section 6.4.3.4.) the argument is applicable here as such restitution processes can be extremely expensive to undertake. This is explained by PN04:

PN04: *"this is one of the big problems for the industry. I think they have got one or two really big Elephants in the room if you like that they haven't tackled and I think that's one of them. And I think they are looking at it and talking about bonds and insurance schemes, um, but I think that's what particularly concerns people because as they looking at the assets of the companies that are making the planning applications and a lot of them are in in they have negative* *assets they actually owe money they are very small offshoots of some in some places quite small operations, in other cases bigger operations. Um, but but you look at a company which has assets if you're lucky of £200,000 and you think, how is that going to clear up a contaminated aquifer? (short pause) for example. It's not. You know that is going to cost millions..."*

Here, PN04 states that payment for environmental restoration of contaminated land is an "elephant in the room" for the UHF industry in that, there have been no answers given with regards to who is responsible for providing funds for environmental restoration. In PN04's view, it would cost millions to "clear up a contaminated aquifer". This thought is shared by Dutzik et al. (2013: 10) who state that 'groundwater contamination is so difficult and expensive to clean up that remediation is rarely even attempted.'

As well as expensive costs of cleaning a water aquifer from any resulting contamination, drilling companies in the United States have had to supply replacement sources of water to households in Colorado after the natural gas contamination of the West Divide Creek, which cost the company $350,000 in 2006 (Dutzik, 2013: 10). In the UK, it is the responsibility of the operator to restore contaminated land. However, if an operator is unable to pay, regulations state that the responsibility then defaults to the landowner to provide aftercare (Department for Communities and Local Government (DCLG), 2014), which is extremely concerning from environmental, ecological and species justice perspectives.

Alongside the groundwater contamination that may occur from surface spills, participants were also concerned with well integrity and, more specifically, that a lack of well integrity (or well integrity failure) could result in the contamination of water aquifers, which will now be discussed in more detail.

5.2.3.2. *Well Integrity and Water Aquifers*

The concern surrounding well integrity and water aquifer contamination is a simple one. Essentially, wells are cased with an MBS in UHF operations (see Appendix Three) which includes mixtures of cement and steel casings. The purpose of such casing is to prevent any substances from the hydraulic fracturing process (such as fracfluid, wastewaters, naturally occurring elements from deep underground, or methane itself) from escaping from inside the well and thus causing such substances to be present, and contaminate, the natural environment, including water aquifers (Meegoda, et al. 2016: 2).

Section 5.2. concluded that vertical migration of fluids from fracture locations up into water aquifers is extremely unlikely due firstly to the depth of hydraulic fracturing (proposed in the UK, compared to the comparatively shallow depth of US water aquifers) and second to the overlying geologic pressure which causes induced fissures to close. However, both participants in the research, and academic research alike, alludes to the idea that water aquifers can be contaminated from UHF operations if well integrity is compromised. This means that, whilst casing is designed to contain substances and prevent them from leaving the well, contamination can occur if well casings fail in such a way as to let substances escape through deformations in the well casing. Such contamination would have negative consequences for groundwater, organisms and animals that survive within, or rely upon, such groundwater or sub-surface geology. This is explained by PN14:

PN14*: "if you pollute groundwater it is very difficult to clean up. So, yeah and it's not only just the drinking water resources it's, you know, pollution of the wider environment and any organisms that are in it and that feeds up the food chain into soils."*

Similarly, PN05, an academic geologist, confirms that well integrity issues could “allow fluids to flow out of the well and into an aquifer”:

PN05: *"well integrity in the long-term, well integrity is a bigger concern, um, because if there are any, um, leaks or any, um, integrity issues that allow fluids to flow out of the well and in to an aquifer um then of course that could be a concern. So I think the well integrity of a longer timescale is something that would be the area that I would be more concerned about in terms of aquifer impacts."*

PN05 also notes that the well integrity of a longer timescale is something that he “would be more concerned about in terms of aquifer impacts”. This is because, cement and steel, the components used in well casing, are not perfect solutions to containing substances. Cement can crack and steel can corrode over time which could lead to produced water (a lot of which remains in the ground after hydraulic fracturing processes have been completed[20], or may be re-introduced into the ground via the well as a wastewater treatment solution[21]) contaminating water aquifers and surrounding subsurface geology. According to Merrill and Schizer (2013: 185):

> ‘There is a risk that the well itself might crack at or above the water table, allowing fluid to leak into nearby wells or aquifers. If there is a crack in the well casing (the layers of steel and concrete encasing the well), then what is inside the wellbore—whether it is fracturing fluid, gas, or oil—could leak out.’

[20] Although the percentages of flowback quantity vary substantially (and depend on geologic conditions, the fracfluid content and quantity, and the operator), ‘it seems certain that a substantial proportion of the fracking additives injected remains underground’ (Bergmann et al. 2014: 9).

[21] Re-injection of produced water into abandoned wells is just one solution for such wastewater disposal. Other solutions include, release into nearby waters (Friedmann, 2013: 11) (which could include, for example, rivers, canals, or the sea), re-use in further fracking operations, or on-site and/or off-site treatment (Stuart, 2014). Wastewater disposal will ultimately depend upon consultation between fracking companies and the Environment Agency.

There are also other factors (other than produced water) that can lead to the corrosion of steal or the demise of concrete strength. Jackson et al. (2014: 339) suggest that, whilst chemical inhibitors are used in hydraulic fracturing fluids to reduce steel corrosion, 'steel corrosion is the most common chemical attack on wells'. Similarly, in relation to cementing, Jackson et al. (2014: 339) note that:

> 'Poor primary cement can occur by the development of fluid channels, casings that are not centred in the well, poor bonding and shrinkage, and losses of cement into the surrounding rock. Well operations can also damage cement through temperature and pressure changes. Examples include the insertion and removal of equipment in the well (tripping), pressure testing of casing strings, hydraulic fracturing, and production or injection of fluids of contrasting temperatures.'

The following quotation from PN08, a law academic, agrees with much of what has been said in this section regarding the potential for water aquifer contamination. Firstly, PN08 agrees that, where casing is inadequate, substances can "leak out of the well". Secondly, PN08 agrees that there is not really a concern with regards to upward migration of induced fractures, "particularly given the depths at which they are fracturing". Thirdly, PN08 agrees that the more problematic issue surrounds inadequate well casing and deterioration of the well materials over several years which can lead to well leakage. Finally, PN08 reiterates that above-ground contaminations may occur, for example, if "someone drops something at the site". These issues can be seen in the following quotation:

PN08: *"the issue, not just with unconventional wells but with conventional wells as well is where the casing isn't adequate so things leak out of the well. So, with the concerns, and this is what the Royal Society said in 2012, is that it's not so much a concern from the fracturing itself so it's not expected that all these nasty things are* *going to migrate into the water directly from the fractures, particularly given the depths at which they are fracturing and the fact that, kind of, the rocks formations, unless you have got pressure conditions present all the time, they are unlikely to fracture further so the distance between an aquifer and the top of a fracture is not likely to be problematic. What's likely to be more problematic is if your casing is inadequate or it deteriorates over years and things start leaking out, or someone drops something at the site. Um, and I think those are more of the potential risks and I think there is this kind of recognition that well casing is actually a big problem in conventional wells and that's the biggest area."*

PN08 concludes the quotation by stating that there is a recognition regarding the importance of well integrity issues, and that this is “a big problem in conventional wells”, as well as unconventional wells. The significance of this statement is that unconventional hydraulic fracturing (due to the nature of the technique and the technological advancement from conventional drilling solutions) requires greater induced pressures, and greater quantities of substances, in order to successfully retrieve hydrocarbons from shale formations (in contrast to conventional wells). PN08 is correct in stating that well integrity is a problematic issue within conventional wells according to academic research. For example, when comparing well integrity in both conventional and unconventional wells, Jackson et al. (2014: 337) explain:

> ‘Today’s unconventional wells are typically longer, must curve to travel laterally, often access substantially overpressured reservoirs, and must withstand more intense hydraulic fracturing pressures and larger water volumes pumped underground than do traditional conventional oil and gas wells. Poor well integrity costs money and can impact human health and the environment. In well leakage, fluids (liquids or gases) can migrate through holes or defects in the steel casing, through joints between casing, and

through defective mechanical seals or cement inside or outside the well.'

Similarly, Boothroyd et al. (2016) studied 102 (66%) of the existing conventional onshore wells in the UK drilled to exploit conventional hydrocarbon reservoirs, wells varying between 8 and 79 years of age, existing within 4 different oil and gas basins around the UK. They found that 30% of the 102 wells had 'soil gas CH4 at the soil surface that was significantly greater than their respective control area'[22] (Boothroyd et al. 2016: 464). Although Boothroyd et al. (2016) still could not definitively determine the source of such methane concentration, they interpreted the results to represent well failure (i.e. if a well had not failed, then no methane would be detectable around the well).

However, interestingly, Boothroyd et al. (2016: 468) also found that, in 39% of wells, soil gas CH4 was significantly lower 'than their respective controls indicating that soils on some decommissioned sites would act as a net CH4 sink.' This means that 'estimated fugitive emissions from decommissioned wells are less than that for the agricultural activities[23] that would take place on the reconstituted land' (Boothroyd et al. 2016: 468). Despite this, the fact that 30% of wells showed significantly higher rates of methane concentration alludes to the idea that well integrity failure had occurred in these wells. Finally, Boothroyd et al. (2016: 468) found that: 'the relative CH4 concentration above wells did not significantly increase with the age of the well since drilling and 40% of the most recent wells surveyed showed leaks implying that leaks develop early in the post-production life of a decommissioned well.'

It is clear then, that unconventional wells require more pressure than conventional wells (Jackson, et al. 2014), and must be fractured

[22] Control areas were 'the nearest field of the identical land use' (Boothroyd et al. 2016: 464).
[23] i.e. sheep grazing.

many more times due to the low permeability of unconventional formations (Suárez, 2012: 125). Additionally, whilst casings provide water aquifers with some protection, leaks may occur as a result of inadequate casing or failed casings (Gold, 2012: 2) (the latter over longer time periods). PN13, a consultant geologist, confirms this stating that problems can occur where the borehole is not appropriately sealed and cased, which can lead to leaks:

PN13: *"when you drill through that aquifer, what you do is you case the hole so the hole is cased and concreted so there is no place for the gases or chemicals to leak out into aquifer. Where you do get a problem potentially is where that borehole is not appropriately sealed and cased and then you get a leak, and that's the problem. That's where the problems occur."*

PN09, from a regulatory body, also states that the risks relating to fracking come from "well design and integrity":

PN09: *"in principle, it should have no more impact than conventional oil or gas activity. Um, the impacts which could potentially come, as I understand it, the risks relate to, um (short pause), well design and integrity. Um, and that's got nothing to do with fracking that's just the question of driving a hole down through geological layers that intersect aquifers."*

However, PN09 also states here that, in principle, fracking should have no more impact in unconventional wells than it does in conventional wells. What PN09 is trying to say here is that both techniques are very similar (i.e. they require a well to be drilled into the ground and that well needs to be cased). However, PN09 fails to recognise two main differences that affect the integrity of wells more so in unconventional wells that in conventional wells. Firstly, unconventional wells target more impermeable reservoirs meaning more pressure is needed to fracture the formation to release the oils or gases trapped inside (compared to conventional formations which are generally much more permeable) (Jackson et al. 2014: 337).

Secondly, PN09 fails to recognise that geologic pressure increases with depth (Aydin et al. 2012: 972). Due to the fact that unconventional formations are generally deeper than conventional ones, there is more geologic pressure and therefore more pressure must be anthropocentrically manufactured in order to induce fissures in deep impermeable strata (such as shale) as opposed to shallower, more permeable strata (such as sandstone and limestone) where less pressure is required to access hydrocarbons. PN16, an oil and gas professional, alludes to the influence of geologic pressure in the following quotation:

PN16: *"Quite often the aquifers that we want to exploit are, are at lesser depth. There is a reason for that which is, the deeper you go the hotter it gets, the more minerals you will dissolve, the trickier it gets to use that water for anything that we want to use it for. So, it's the mineral content, quite often the water we get from wells that are 3 kilometres deep, gas wells, the water that comes up with it is brine. It can even be more salt laden than sea water. So, it is very little use to us."*

Here, PN16 explains that the water aquifers that are useful to humans (i.e. to provide drinking-water) are situated at shallower depths than deep aquifers where the groundwater is largely brine and, therefore, of very little use to humans.

From a regulation perspective, PN17 explains the importance of well integrity for "people and the environment":

PN17: *"if they lose control of the well then that can have a big impact on the people and the environment, so they are very focused on* *making sure they maintain that well integrity, um, throughout the lifecycle of the well."*

This section on the relationship between well integrity and water aquifers has revealed that, whilst cement and steel casing is exceptionally important in protecting water aquifers from contact with fluids and gases present within wells during hydraulic fracturing operations, the high pressures used in the process have the potential to cause well failures whereby cement or steel casings are affected in such a way as to provide contaminants with a pathway through casing into water aquifers.

Whilst soundly implemented casings provide a shorter-term solution to providing effective well integrity, the fact that cement can deform and steel can corrode over time (combined with the fact that much flow-back water either remains within wells or is re-introduced into wells), means that, well integrity is a concern over the longevity of wells, particularly after decommissioning and abandonment (this is confirmed by Boothroyd et al.'s (2016) study of methane presence in soils surrounding abandoned onshore conventional wells in the UK).

The following section (5.2.4.) goes on to discuss other interesting codes that were given by participants concerning the potential for UHF to affect water aquifers.

5.2.4. <u>Other Codes</u>

The first interesting quotation comes from PN06 (a social science academic) who suggests that problems with fracking and water aquifers stem largely from wellbore design and construction, as opposed to anything fundamentally wrong with the hydraulic fracturing process itself:

PN06: *"if you talk to industry people they will say well actually your problem is an engineering problem. That when you are doing your fracking you are way below an aquifer so any methane or fracking chemicals which leak into an aquifer will be problems with well bore construction and the lining of the hole you are drilling. Um, you know if you get cracks in the concrete that's when things start to leak. So it's basically a function of how well designed a wellbore is as opposed to something being fundamentally wrong with the hydraulic fracturing itself..."*

In contrast, PN14, a consultant to the water industry, believes that the UK have taken a precautionary approach to the protection of groundwater:

PN14: *"the protection of aquifers should be the most important thing. And originally, they weren't properly protected, so we actually lobbied the Infrastructure Act and managed to get that commitment that they won't drill in source protection zone 1 and, er, if they are doing a horizontal drill it will be under 1200 metres and I think it is quite good that we have got that precautionary approach. Um, we've also got the EA which permit everything and they are a strong regulator and I genuinely believe they will reject any application that has a risk to groundwater."*

There are three points to note here. Firstly, PN14 rightly states that fracking is not permitted in ground source protection zone 1 in the UK. This is because s.50 of the *Infrastructure Act 2015* stated that fracking will not take place within 'protected groundwater source areas' which further regulation has been extended to include source protection zone 1 (Davidson, 2015)[24].

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[24] More clarity is provided on this by Davidson (2015: 38) who states that: 'regulation 2 of the Protected Area Regulations set out 'protected groundwater source areas' as within 50m at the surface of an abstraction point used for domestic or food production purposes or within the 50-day ground water travel time for such an abstraction

Secondly, horizontal drilling is not legally permitted shallower than a depth of 1000[25] metres below surface level (see, s.50 of the *Infrastructure Act 2015*). The reasoning behind this is to make sure there is an acceptable distance between shallow aquifers and hydraulic fracture locations to prevent induced fissures from extending vertically upwards into water aquifers (as discussed in section 5.2.2.2.).

Thirdly, PN14 states that the EA is a strong regulator and she "genuinely believe(s) they will reject any application that has a risk to groundwater". Although PN14 describes the EA as a strong regulator, the phrase "genuinely believe" could be interpreted as meaning that regulatory agencies (or the EA specifically) have in the past accepted applications that pose environmental or human risk. However, the extent to which regulators are effective in their roles in managing human and environmental harm, is beyond the scope of this project.

Another important point relating to water aquifers is the complex geological conditions present in the UK, and the inability of those involved with fracking to keep track of the exact whereabouts of fracfluids and chemicals underground. PN20 suggests that the UK's geology is highly faulted and unpredictable:

PN20: *"the problem in the UK, um, is that our geology is unbelievably complicated, it has got lots of faults in it. I mean, I have been to some of those fracking locations in America and the geology stays the same for great tracts for hundreds of miles. Um, the geology isn't like that here. The geology here is utterly unpredictable. We don't even know what the geology is like a hundred, two hundred feet under our*

point. This effectively corresponds with what is known as Source Protection Zone 1.'

[25] Not 1,200 metres as suggested by PN14.

feet, despite mapping since the Victorians, because of the complexities of the faults and the past mining. So, we have no idea, um, where it will go..."

PN20 gave his response in relation to the question asked of him concerning the potential impact of UHF operations on water aquifers. The interviewer is therefore confident that, whilst PN20 does not specifically mention water aquifers within this response, that he is indeed relating the complexity of the geology to an unpredictability of water aquifer contamination due to the fact that it is impossible to keep track of where substances may go underground. Importantly, PN20 suggests that this situation is different (and less risky for water aquifers) in the US where the geology is much more consistent.

The penultimate quotation regarding water aquifers, again from PN14, is important as she suggests that industry does not want to cause pollution:

PN14: *"I think the industry you know, the last thing they would want to do is pollute an aquifer, it would just completely ruin their license to operate."*

Whilst legal industrial processes do often create varying levels of environmental harm and contamination (such as the production of coal, steel, or concrete), it is arguably not the direct intention of such industries. Instead, environmental harm can be seen as a consequence of human interactions with the environment, a consequence of the treadmill of production.

PN14 (above) also uses the term “ruin their license to operate” with regards to a fracking company polluting a water aquifer. The (lack of) a social license to operate is a very contentious issue within UHF in the UK as the government has reported consistent public opposition to shale gas fracking (DBEIS, 2018), despite supporting fracking, passing the *Infrastructure Act 2015*, and providing tax-breaks to fracking operators to encourage investment (Cotton et al. 2014: 427). Therefore, it is clear that PN14 believes that polluting an aquifer would (further) “ruin” a company’s license to operate.

5.2.5. Conclusion

The analysis for water aquifers in this section (5.2.) has concentrated on four main points each brought up in several interviews. Firstly, wells are cased with MBS’s (made of cement and steel) in order to prevent fluids and gases from escaping the well and contaminating aquifers. It was then shown that, whilst such casings are extremely important in preventing aquifer contamination in the short-term, in the longer term, casings are not always entirely effective in preventing contamination because steel can erode and concrete can deform over time.

Secondly, it was shown that most participants were of the view that, because of the depths of fissures in shale (compared to the correspondingly shallow depths of useful aquifers), upwards vertical migration is unlikely to provide substances with a pathway from deep fracking locations to shallow aquifers. Although geological faults can provide alternative pathways, significant geologic pressure should prevent fissures from extending far enough upwards to contaminate aquifers.

Thirdly, a more realistic risk of environmental contamination comes from surface spills (for instance in the form of truck accidents or handling on site). Finally, and arguably the most important issue with regards to the potential for fracking to contaminate water aquifers, is concerned with well integrity. Most participants were of the view that good well integrity is pivotal in preventing the release of fluids and gases into water aquifers and that well failure or well deformation can lead to the contamination of aquifers. Specific issues regarding well integrity will be analysed further in Chapter Six (section 6.4.).

5.3. **Deductive Category Two: Water Resources**

5.3.1. Introduction

Participant responses can be narrowed down into two succinct categories in respect of their answers to the question posed of them concerning water resources (see Appendix Seven). Firstly, several participants explained that they thought fracking would have very little, or no effect, on the UK's water resources. Secondly, several participants were of the view that fracking would have a negative effect on the UK's water resources. This section is split into these two sub-groups because no participants expressed the view that fracking would have a positive effect on the UK's water resources. The first section (5.3.2.) will consider the extent to which fracking may have very little, or no effect, on the UK's water resources, based on a combination of participant responses and academic publications.

5.3.2. Fracking May Have Very Little, or No Effect, on the UK's Water Resources

Largely, participants did not believe fracking would have any great effect on the UK's water resources. Whilst this section (5.3.2.) will outline the concerns that participants had, even these participants did not believe that water resources were the main issue related to fracking where environmental and social harms are concerned. In fact, many participants did not have any concerns about water resources and gave very limited responses. This can be seen in the following quotation from PN01:

"**I**: *What impact do you think that fracking will have on the UK's water resources?*

PN01: *Very little.*

I: *Ok.*

PN01: *I mean it's a large amount judged by someone's bathtub but it's not a large amount really."*

Although PN04 questions the extent to which using water for fracking can be seen as a "good" use of the water supply, she notes that "water companies are relatively relaxed about it", and, in terms of absolute water demand, fracking will not have a great effect on UK water supplies:

PN04: *"the water companies are relatively relaxed about it. I think it could have local impacts so there will be parts of the country where water is more of a problem, water supplies are more of a problem, and other areas are in the stage it's not going to have any impact on water supply. Whether you think it is a good use of water of course is another question. Um, but um, in terms of absolute water demand I don't think, I don't think it's going to have, certainly not in the initial stages."*

PN09 notes that the requirement for water for fracking processes is a "temporary" one, explaining that fracking is a very short-lived activity:

"PN09: *most of the water that is used is recovered at the surface and then cleaned up and/or disposed of. So, there is some temporary requirement for water but again fracking itself is a very short-lived activity. If people think that fracking is something that, you know, you start fracking on day one and in continues for 25 years, it doesn't. And there are plenty of industrial activities that require quite large amounts of water, er, not least for cooling purposes..."*

Whilst chemicals and proppant (sand) can be used to keep fractures open for as long as possible, the overlying geology above shale (which exists at approximately 3 kilometres in depth in the UK) is constantly exerting a downward force causing the hydraulically induced fractures within shale to close. This means that (without re-fracturing) the same horizontal formation, induced fractures do not stay open (providing a flow of gas) for very long. This leaves operators with two options. Firstly, they can close down and decommission the well and move on to drilling a different well elsewhere. Alternatively, providing that the original well has not failed and is in good condition (and subject to further licences and regulatory controls), an operator could use the same well to drill a separate (or multiple) lateral extensions in order to produce more hydrocarbons from the same site. Speight (2013: 94) notes how such technological advancements (that is, the ability to multi-fracture a well) have numerous benefits both environmental and socially:

> 'This increase in reservoir exposure creates a number of advantages over vertical well drilling. Six to eight horizontal wells drilled from only one well pad can access the same reservoir volume as sixteen vertical wells. Using multiwell pads can also significantly reduce the overall number of well pads, access roads, pipeline routes, and production facilities required, thus minimizing habitat disturbance, impacts to the public, and overall environmental footprint.'

Despite this argument, it is obvious that a multiwell pad would create significantly increased social and environmental harms than a singular well pad that only conducts vertical drilling or one horizontal extension. Multiple lateral extensions would require many more truck movements due to the need to import more sand, more chemicals and more water, as well as transporting more facilities and equipment to and from the site and removing much larger volumes of wastewater. Therefore, whilst Speight (2013: 94) is correct in stating that the overall number of well-pads would be significantly reduced, he fails to make any critical acknowledgement of the increased intensity that a multi-well pad would create and the effects that this would have on people, non-human animals, and the environment more widely. It is also worth mentioning that using high pressure for multiple extensions within the same wellbore would significantly increase the prevalence of well failures in those wells. A multi-well pad would also require greater storage capacity for chemicals, water and sand used within hydraulic fracturing fluids, leading to a potential increase in the size of a multiwell pad compared to the smaller size of a single-extension well pad.

PN13, a consultant geologist, explains that the water used for fracking processes is very little compared to other processes:

PN13: *"So, again in actual fact, the amount of water used in fracking is relatively low. People think it's a huge amount but relative to other things it isn't."*

Additionally, PN13 goes on to say that, where there is competition for water resources (i.e. in water-stressed areas) fracking would not be a high priority compared to other processes, such as agriculture:

PN13: *"in water stressed areas there is a possibility that the Environment Agency wouldn't give you a license because they will assess your abstraction for water for fracking on the basis of all the other needs in the area and public water supply obviously, and agriculture comes first. So, you may be low down on the pecking order in order to get one. However, the actual amount used is relatively low. So, for example, a frack site might use, um, what a, um, I looked at these figures, might use what a golf course uses in a month. So, it's not a big impact on our water supplies, ultimately."*

However, PN06 suggests that the main areas in which operators are currently looking to conduct UHF (the North-East and North-West of England) do not tend to be water-stressed areas, compared to other parts of the UK:

PN06: *"I think one of the advantages of UK fracking is that it's predominantly in the North-West and North-East of England that don't tend to be as water stressed as say somewhere like Norfolk or the South-East..."*

Despite this, PN06 goes on to suggest that the volumes of water used for UHF are quite significant so the access to water depends on the regional state of water resources:

PN06: *"the volumes of water are quite significant. Um, so it really depends on, um, on the regional state of the water resources available..."*

Furthermore, PN06 questions how water may be prioritised in regions that are water-stressed, and whether this could result in higher water prices or less access to clean water:

PN06: *"my concern would always be, well who loses out in those situations where water stressed regions are then fracked? Does that mean higher water prices which means less access to clean water?"*

PN14, a water consultant, makes an extremely important point when it comes to water extraction. Essentially, PN14 states that fracking operators will source water from water companies when supplies are plentiful, storing the water ready to be used when hydraulic fracturing begins. This enables a fracking company to manage their water needs with the needs of the local area, which is particularly significant in times of drought:

PN14: *"I think, again, it has been slightly over exaggerated by people who are opposed to fracking, I don't think it will have a big impact because I think it will be controlled quite well and, you know, we have extraction management by the Environment Agency so they will determine how much water can be taken out and if they are going to* *buy it from a water company obviously, the water company would have to agree depending on how much water they have available. Um, so I think it will be controlled there. I think the industry have got a certain amount of control because they can choose when to use the water, when to time the fracture. Um, they only need it for drilling and fracturing stage obviously and production they re-fracture they don't need any water. So, they can um, get it on-site, source it when it is plentiful and have it ready to go and use it, um, and then in times of drought I think they can manage it if they need to."*

Finally, PN16, an oil and gas professional, argues that water resources are based on market forces:

PN16: *"I think we will be ok with that, based on market forces. So, if fracking required such vast quantities of water that it would impact water companies, water companies would want to be recompensed for that and you would find a balance being created by those who want to supply and those who want to consume for this purpose, and there would be a premium on it for this purpose, um, because water companies would not want not be left out of the loop if you like. So, I think the, the actual water there is, there are means, ways and means for water management in the UK to be improved still. Um, so I don't believe we will have a great problem with that."*

This section (5.3.2.) has analysed participant responses surrounding the UK's water resources with particular focus on responses that convey the opinion that fracking will have very little (if any) impact on the UK's water resources. Although interviews did not bring to the surface many significant debates in this area with regards to social and environmental harm, some participants did bring up some interesting points for consideration. It must also be borne in mind at this stage that no participant responses described any possibilities or eventualities where fracking would have a positive effect on the UK's water resources. The next section (5.3.3.) will consider the potential negative effects that fracking may have on water resources.

5.3.3. Fracking May Have a Negative Effect on the UK's Water Resources

Firstly, PN04 inferred that there is a carbon cost involved with ensuring that water is of significant quality to be consumed by humans:

PN04: *"there's a carbon cost to, um, making water to a high enough quality to drink and should we be using water that is good enough to drink to frack a well? I personally have questions about that. Um, I'm not sure it's a good use of the water and I'm not sure it's a good use of the carbon involved in the processing of that water..."*

Importantly, only fresh water can be used to hydraulically fracture a well. Seawater cannot ordinarily be used because of its salinity which could corrode well-casing (Nicot and Scanlon, 2012: 3585) leading to well failure. Fresh water will not cause casing problems in the short life-time of a well. However, fracking does use around 5 million gallons of water per well (Prud'homme, 2014: 73) producing various amounts of produced and flow-back waters that need to be treated at a wastewater treatment facility. The process of treating wastewater and transforming it to water that meets drinking-water requirements, in itself requires energy. This is exacerbated by the carbon cost involved with transporting water and wastewater to and from a fracking site in large tankers powered by diesel. The total carbon cost is impossible to say at the time of writing because the amount of water used (and therefore wastewater generated) is influenced by the number of fracking wells that are developed in the UK. These thoughts are acknowledged by PN05, an academic geologist:

PN05: *"the water supply, um, and the disposal of waste water, um, at the surface. And that again is going to come down to a combination of, um, the size of the project and how much fracking takes place around the UK generally and you know it's a water intensive process but, um, how many fracking sites actually get going will have a big impact on the overall water demand..."*

Whilst the quantity of water remains a concern in the UK, particularly in an era with increasing human populations, water is less of a concern here than in other, more hostile areas of the world such as Australia and the United States (two nations that conduct hydraulic fracturing that also struggle with competing water demands). Prud'homme (2014: 72-73) regards this as one of the three biggest concerns in terms of water supplies explaining that:

> 'hydraulic fracturing uses so much H2O – about 5 million gallons per well, on average – that it can deplete groundwater supplies faster than nature can recharge them, especially in dry regions like Texas or California.'

PN08, a law academic, explains that operators acquire water from utility providers and therefore the quantity of water (and their priority for obtaining it) is controlled by utility provider policy, rather than by legislation:

PN08: *"any sort of industrial process does use a lot of water. But I think the issue is, if water companies are extracting water they get a license which says you can only extract this much water and you can't take any more than that. But what they are doing at the moment, they are sort of getting it from utilities providers. So, what that means is that, the quantity of water and their priority for getting water is no longer controlled by legislation, it is controlled by utility provider policy. Um, so I guess in areas such as the South East where they do have more of an issue, um, with water shortages, that* *is a potential because it depends where on the priority list these companies come."*

Therefore, according to PN08, competition for water could become a problem in water-stressed areas (such as the South-East).

Finally, PN20 suggested that the UK does not have great reserves of water that are freely available, concluding that both ends of the water equation have not been thought through (access to water resources at one end, and disposal or treatment of wastewater at the other):

PN20: *"We do not have millions of gallons of, er, clean water, er, freely available, er, to just turn the taps on. So, both ends of the equation have not been thought through."*

5.3.4. <u>Conclusion</u>

In conclusion, participants were generally of the view that fracking will not have a great impact on the UK's water resources, particularly when the water volumes used in fracking are compared to other industrial practices. However, participants did bring up some important concerns with regards to water use, such as the carbon cost involved with both transporting and treating water and wastewater that is used in fracking processes.

This section will conclude with a quotation from PN12, an anti-fracking campaigner. He explains that fracking entails costs (both socially and environmentally) which are accrued by the fossil fuel industry generally, and that fracking would be part of that:

PN12: *" the UK could survive that amount of water extraction but do you really want to? It's, it's a cost fracking, um, that is, well a question of do you want to pay it? And one thing is, it's not a defence of fracking, but a criticism of the fossil fuel industry generally, coal* *and gas fired power-stations use even more water than that. So, the total water consumption of the fossil fuel industry is something to be worried about and which fracking would be a part, only a part."*

5.4. **Deductive Category Three: Wastewater**

5.4.1. Introduction

Prior to displaying and interpreting results, it is important to understand terminology with regards to wastewater as several different terms with different meanings are often used interchangeably when referring to issues around wastewater treatment and disposal. For the purposes of this research, the following three terms will be used; wastewater, produced water and flow-back water.

Firstly, the term wastewater is adopted as a generic term that describes all forms of wastewater including produced water and flow-back water. Secondly, the term produced water will be used to describe a specific form of wastewater. According to Jackson et al. (2014: 342) produced water can be defined as 'the fluid that flows to the surface during extended oil and gas production'. This produced water is therefore a mixture of the original fracfluid used within oil and gas operations, as well as the brines, organisms, bacteria and geologic composites that exist within the target (shale) formation. Such composites include NORM's and VOC's which are extremely difficult to treat at wastewater treatment facilities (O'Donnell et al. 2018). Finally, flow-back water can be defined as:

> 'the fluids that return to the surface after the step of hydraulic fracturing and before oil and gas production begins, primarily during the days to weeks of well completion' (Jackson et al. 2014: 342).

Flow-back water generally consists of 10-40% fluids and chemicals used in the process and the rest consists of natural brines originating from within the earth's geology (Jackson et al. 2014: 342). Therefore, the differences between these two terms are that they are both wastewaters but they are produced at different stages of the UHF process.

Codes emanating from participant responses to the question asked of them regarding wastewater disposal (see Appendix Seven) can be categorised into four succinct sections for the purposes of results formation and analysis. Firstly, section 5.4.2. will address those codes that concern the treatment of wastewaters. Secondly, section 5.4.3. will consider temporary surface storage of wastewaters and transport of such water to wastewater treatment facilities. Thirdly, section 5.4.4. will deliberate participant responses regarding the potential for re-injection methods to be utilised as a form of wastewater disposal and as an underground storage solution. Finally, section 5.4.5. will discuss other codes that are of interest to the research, but do not necessarily fit within the other three categories.

5.4.2. Wastewater Treatment

Often during UHF operations, wastewaters are not of a sufficient water quality to enable the operator to discharge the wastewater into natural water cycles (rivers, streams, canals etc). This is because wastewaters often contain chemicals used within UHF operations, as well as other geological matter collected from below the earth's surface. According to a report published by the RSRAE (2012: 20):

> "Approximately 25% to 75% of the injected fracturing fluid flows back to the surface when the well is depressurised. This fluid is mixed with methane and saline water containing minerals from the shale formation. The volume of flowback water depends on the properties of the shale, the fracturing design and the type of

> fracturing fluid used… Produced water will continue to return to the surface over the well's lifetime. These wastewaters typically contain salt, natural organic and inorganic compounds, chemical additives used in fracturing fluid and NORM… Very little is currently known about the properties of UK shales to explain what fraction of fracture fluid will return as flowback water, as well as the composition of formation waters and produced water."

Wastewaters are deemed to constitute 'extractive waste' and are therefore regulated under the Mining Waste Directive (MWD) (Hawkins, 2015; 14). Under this regulation, operators are required to assemble waste management plans and obtain permits from the EA. These plans will vary according to the constituents of the wastewater which will depend on local geological properties and whether pre-treatment is necessary (or has occurred, on-site) (RSRAE, 2012: 21).

In general, participants were aware that wastewater is likely to go through this regulatory process that most likely requires wastewater to be treated at specialised, licensed, wastewater treatment facilities. This is shown by PN01:

PN01: *"it's supposed to be tankered away and er (short pause) as far as as far as I know and has to be disposed of at a licensed site."*

However, despite a seemingly robust regulatory system, PN03 (an anti-fracking campaigner) suggests that wastewater treatment does not necessarily rid wastewater of "radiation", "chemicals" or carcinogens:

PN03: *"if they put it through a normal waste water treatment, well they are not getting rid of radiation (short pause) that doesn't go away. You know and certainly a lot of the chemicals that come up actually become more toxic and more carcinogenic when they are put through some form of treatment."*

An example of the difficulty in treating wastewater is considered by O'Donnell et al. (2018) when discussing the disposal of NORM's. O'Donnell et al. (2018: 325) suggest that such treatment could be very expensive and, whilst NORM is produced through other industrial processes, treatment at specialist facilities 'will pose management problems if wastewaters are generated from multiple unconventional wells simultaneously.' A difficultly in treating NORM specifically is that 'dissolved NORM may settle out to form solid wastes, such as mineral scale on the inside of wells and pipes or sludge that accumulates in storage or treatment tanks' (RSRAE, 2012: 22). This means that there are additional treatment and disposal problems surrounding NORM which may consequently be dealt with through re-injecting into a disposal well (RSRAE, 2012: 22) or paying to dispose of NORM at a landfill site (O'Donnell et al. 2018: 325)[26].

Furthermore, PN04 states that there may only be a limited number of wastewater treatment facilities in the UK that have the ability and required licences to accept wastewaters generated by UHF processes:

PN04: *"I think that's another Elephant in the room. Um, there's a really good, um, argument that Friends of the Earth used at the Cuadrilla enquiry, they got a paid consultant to look at Cuadrilla's plans. Cuadrilla wouldn't say which water treatment works it was proposing to send its wastewater to, um, but this guy worked it out based on a parliamentary question and an answer. The two water treatment works which he said were the only ones that could cope, ones at Leeds and ones at Stoke-on-Trent. Um, and one of the key issues is what the concentration of the waste chemicals in the water will be because the treatment plants are licensed up to certain concentrations of particular chemicals. If there were chemicals at*

[26] The option chosen by the operator will likely depend on various factors including cost and permitting.

greater concentrations than were allowed in the permits for these treatment facilities then it may be that they wouldn't be able to take the waste from Cuadrilla's fracking site anyway so that's an issue and it also may mean that the water treatment facilities would be over the limit for the amount of particular components that they can take. So it may mean that other customers are not able to dispose of their waste and Cuadrilla was estimating I think it was 60% of water treatment capacity. Now they have been talking about it locally but actually it was at these water treatment plants, um, which were the only ones that were licensed to take the sort of material that Cuadrilla is likely to produce."

PN04 describes this situation as an "Elephant in the room" for the UHF industry in the UK. This is an adequate description for the current situation on wastewater treatment because of the low-capacity of wastewater treatment capability (particularly of NORM) in comparison to the amount of waste that may be generated by multiple wells operating simultaneously. Whilst PN04 suggests that there are only two sites in the UK that could cope with Cuadrilla's planned wastewater treatment solutions, O'Donnell et al. (2018) suggest that there are four treatment facilities in the UK that are appropriately permitted for to handle waste containing NORM. These include: Knostrop, Leeds; Northumbrian Water Limited, Middlesbrough; Castle Environmental, Stoke-on-Trent and a site at Starnhill Close in Sheffield (O'Donnell et al. 2018: 331).

PN04 goes on to discuss that whilst NORM's are generated in the UK by a number of industries and processes, the presence of NORM's in wastewaters "limits the number of treatment plants that it can be dealt with" because only a certain number of sites are licensed to deal with NORM's:

PN04: *"But with the NORM's that is one of the key issues that limits the number of treatment plants that it can be dealt with because, um,* *as I said they are licensed to deal with some materials and only a few of them are, um, permitted as I understand it to deal with more than the level that it is likely to be. I mean Naturally Occurring Radioactive Material occurs all the time and all sorts of industries produce it and services produce it and it has to be dealt with and, I think it's (short pause) one of the limiting factors where their waste can go. And the idea is that the treatment facility would remove the waste and it would only release the treated water, treated fluid, um, at a point at which it would not be a threat to the environment. That would be the basis of the environmental permits of the treatment facilities. (Short pause) INEOS I think is talking about releasing their waste into the Sea after it is treated but it still would be treated."*

In relation to quantities of wastewater, PN04 states that between 30%-70% of fracfluid returns to the surface as produced water over time. This is significant because the initial flow-back water is "so badly contaminated" that it must be classed as low-level radioactive waste. This further limits the number of wastewater treatment facilities that are licensed to accept such wastewater:

PN04: *"Yeah, well I can't remember the exact figures but it's anything from, I don't know, 30 to 70% or something like that, they say come back. It doesn't all come back at the same time it comes back over time. Now, this is a significant point about your water resources is that, once you have taken that water out it's effectively lost from your water cycle, you can't just return it like the farmers can, it goes in the ground, you know (difficult to hear) goes back again. This is so badly contaminated, um, fracking flow back in particular has got so much bad stuff in it, and is classed as low level radioactive waste that it has to go to specialist treatment centres, of which there are only 4 in the UK at the moment."*

PN07, a Parish Councillor, again mentions problems with regards to the contents of fracking wastewaters and the difficulty in treating such wastewater:

PN07: *"it's to what level are they going to actually treat this water. INEOS, er, there was a big newspaper article about 6 weeks ago, INEOS saying that their wastewater they are just going to pump straight into the Sea. But they will say oh no, but that's after we've treated it (difficult to hear). But it's not just what's in there which is your low-level radioactivity but you've got all your BTEC stuff, really toxic carcinogenic things which, you only need a tiny amount of this stuff for it to affect people, you don't need large amounts of it for it to be toxic. It's the sheer amount of that water, if we get into full production, we do not have the capacity in the UK to be able to treat it at the moment. So, what happens? Do we, is that going to be part of the infrastructure? Are we going to build more of these waste treatment facilities? That might be where the jobs come in, a few jobs there I suppose. Or is it going to be backed up and stored in the areas where it is produced? Until they say OK, you can bring another lorry load up now. You know, and that has impacts for local areas as well in terms of potential contamination because that is quite different from the drilling waste and drilling muds that you'll get from exploratory. It's a lot more toxic and contaminated."*

PN08, a law academic, similarly brings to the fore issues around capacity and the ability of companies to deal with large volumes of fracking wastewaters:

PN08: *"the different waste management companies, obviously, some of it will be treatable, um, and there is a possibility of recycling so, if it's being recycled for that process then it's not necessarily too problematic. Um, but obviously, this is the other big issue that comes up a lot is that, a lot of this will have to be sent to licensed, specialised, waste management sites. And if we went into large scale* *production, and actually, it's not clear that we actually have, um, sufficient infrastructure, um, and sufficient companies licensed to deal with the volume of water that they might need to be dealing with. So that's sort of more of a concern than the water it's using is actually, can we manage the waste once it comes back up."*

In relation to capacity, PN08 is uncertain whether the UK has the sufficient infrastructure and a sufficient number of companies that are licensed to deal with large volumes of wastewaters. This begs the question, if the treatment of wastewater is an absolute necessity in terms of protecting the environment, who is responsible for investing in the development of additional capacity (i.e. building additional specialist treatment works)? This is perhaps another *Elephant in the room*.

Similarly, PN13, a consult geologist, suggests that wastewater is the "biggest challenge" for the fracking industry:

PN13: *"I think that's the biggest challenge in actual fact. You obviously get the frack flow, the fracking fluids come back with some other waters from the hole and after that you get flow back which is all the brine waters that were laid down when these shales were laid down in the seas many many, er, millions of years ago. And all that water comes back and that's going to likely contain NORM's which is naturally occurring radioactive materials and those are going to be the challenges I think, absolutely that's a challenge. So, it's water treatment, it's mobile water treatment, potentially recycling and reuse of the water as much as you can but eventually the solids and everything else will build up and, um, it will be less effective. So, yeah, that's definitely a challenge at the moment and it's not been sorted really."*

Whilst PN13 states similar issues of the treatment of NORM's and other materials contained within shales, she also alludes to other potential solutions for dealing with wastewaters which include recycling and re-use of wastewater. The recycling of wastewater could be used if such wastewater has already been treated in some way, or if the solution is diluted (RSRAE, 2012: 21) with more freshwater to reduce the concentration of various materials (NORM's, brines, other organic compounds produced from a well) contained within wastewaters. A major problem with the re-use of wastewaters in UHF processes is the degree of salinity which (whilst this changes over time) can corrode the well leading to complications with well integrity. Although desalination technologies are developing, reusing wastewaters is still extremely problematic. According to RSRAE (2012: 21):

> 'Microorganisms, such as bacteria, can exist even in deep shale formations, and so may be present in the formation water within wastewaters. These microorganisms need to be removed for health and safety and commercial reasons. Bacteria can produce hydrogen sulphide and acids that corrode well casings, and so potentially contribute to well failure.'

Whilst PN13 agrees that wastewater treatment and the capacity of specialised facilities is a problem, again, particularly where NORM's are concerned, she finishes the following code by stating that other sites may be able to obtain a suitable license in the future:

PN13: *"it is a problem, um there's, what you do obviously, the NORM's are associated generally speaking with the solids so you would take the solids out and that reduces obviously, the NORM's in the water. But the solids have to go somewhere. I think there are only two landfill sites in the country, may be three, licenced to take low level, or any level radioactive waste, so, and they're of only limited capacity so that gives us another problem. Um, the water once most of the NORM's have been removed because they are attached to the solids then, um, as I say you are right there are only a few sites that are permitted to take this water and they need a* *radioactive license to do that. That doesn't mean that other sites couldn't obtain a license I think. They may have the technology they just need to obtain a license."*

Although most participants agreed that treatment of wastewater would take place at specialist facilities, PN14, a water consultant, suggested that UHF wastewater is "unlikely" to be treated at a treatment works:

PN14: *"it is unlikely that it will be treated in a treatment works, a water company treatment works. I think they will need to do pre-treatment perhaps on-site, um, or send it to one of those industrial treatment works. And, as I said, I don't think there is enough capacity I think they will, the company will need to, the industry will need to develop their own wastewater solutions..."*

As a result of issues of capacity, PN14 proposes that operators (and the industry generally) will have to develop their own wastewater treatment solutions, but there is little indication of what this may entail besides pre-treatment and surface storage of wastewaters on-site.

5.4.3. <u>Surface Storage and Transport</u>

In addition to problems associated with the treatment of wastewater at specialised, licensed facilities, participants also identified complications around both the storage of wastewaters at surface level, and the transport of wastewaters from place to place (for example, from a production site to a wastewater treatment facility). For example, PN02, an anti-fracking campaigner, interlinks the problems associated with traffic and wastewater treatment which led Cuadrilla to discharge wastewaters into a natural water system after their 2011 operations at the Preese Hall-1 well in Lancashire:

PN02: *"people don't realise that the amount of of traffic in and out of a site taking freshwater in, taking polluted substances out, and they've admitted the fracking companies, Cuadrilla, that they have nowhere to send this stuff, erm, there was only one plant near Manchester that was doing a bit, because they couldn't take it in 2011 what did they do with it? They dumped it in the Mersey, on the Manchester Ship Canal (short pause), now, that's irresponsible, er, in my view, erm, so there's a sort of cyclical issue here about water which I believe is one of the most precious resources for human life and we must protect it at all costs."*

PN02 is correct in stating that Cuadrilla discharged wastewater into the Manchester Ship Canal, which included NORM's (Smythe, 2014: 14; Wood, 2014: 24). This occurred with the consent of the EA but prior to the enforcement of EU regulations that classified flow-back water as radioactive waste in October 2011 (British Broadcasting Corporation, 2014). This suggests that, if the EA will permit the disposal of wastewaters (treated or untreated) to natural water systems, then operators are likely to choose this as a means of disposal (because it is much cheaper than paying for the necessary treatment). Britain's recent 2016 referendum vote to leave the EU could have implications for such regulatory controls. For example, if flow-back water (or other wastewaters) are not classed as low-level radioactive waste when the UK has departed from the EU, this could free-up operators (under the guidance of the EA) to discharge wastes into natural water systems.

With regards to wastewater and transportation, PN04 suggests that the amount of flow-back water and produced water that returns to the surface as a result of UHF operations affects the amount of wastewater that may need to be treated and the amount of transport that is needed in such a process:

PN04: *"there's also the issue of transporting it, um, and Cuadrilla's planning application was based on a certain proportion of waste coming back. I mean, I was at a planning conference where one of its executives said we don't know how much is going to come back we have no idea. At Preese Hall I think it was 70% that was coming back so that's actually quite a lot, um, and they were estimating around 40% you would need to check the figures because I haven't got them in front of me, because if more comes back than what you are expecting then that has a knock on on the possibility of your business because you have a knock on, you have to pay for the water to be treated and you've also got to pay for it to be transported and that affects your traffic management plan as well. Um, so there's a lot of unknowns about waste, um, and a lot of sort of assumptions and a lot of kind of, um, almost hopes for the best..."*

Finally, PN18 suggests that open lagoons at fracking sites would not be used as a storage method for wastewaters:

PN18: *"it would have to be tankered away and they would have to use the right sort of facilities to do that and then obviously (omitted – confidentiality) show the right sort of care when they are actually processing it back up to surface. I mean one thing that is different in this country compared to the States is that we wouldn't allow these sort of, open lagoons where the stuff's there."*

This is confirmed by the EA (no date: 2) who suggest that wastewaters must be retained in sealed tank containers:

> 'In some countries, the waste fluid that flows back up the well to the surface has been stored in open, sunken pits, from which it can leak into surrounding soil, surface water and groundwater. In England, the storage of waste waters in unlined pits is not allowed. All waste waters must be stored in sealed tanks within a retaining wall (known as a bunded area) to prevent surface and ground water contamination.'

5.4.4. Re-Injection and Underground Storage

Besides the wastewater treatment and disposal methods brought up by participants so far, there is a final disposal technique that is a common procedure in the United States and, as a result, was often discussed by participants. This revolves around the deliberate re-injection of wastewater into an abandoned well or a well that has otherwise expended its production lifetime. Re-injecting wastewater in this way may still affect the integrity of the well because of the contents of wastewater, unless pre-treatment occurs prior to re-injection to rid wastewaters of NORM's and other potential corrosives that may affect well integrity.

The EU MWD discussed in section 5.4.2. is also important here. This directive requires flow-back wastewater to be classified and treated as mining waste which necessitates treatment at a specialised facility. The EA (2017: 2) have been very explicit in stating that they will not consent to fracking wastewaters being injected into the ground for disposal. However, were the MWD to be repealed (meaning flow-back does not have to be classified as mining waste), then this may impact the Environment Agency's position on wastewater re-injection as a disposal technique. PN02, an anti-fracking campaigner, postulates an interesting legal point in this area:

PN02: *"I think because of the massive problem of what to do with this big volume of wastewater, um polluted water, um, I think that's why they are going down the route of re-injecting these substances back into the ground. It's interesting that under the 2015 Infrastructure Act, there's a clause in there that says that, any substance can be put back into the ground, unspecified (short pause), which does ring alarm bells for me..."*

The specific point that PN02 is referring to within the *Infrastructure Act* 2015 is contained within s.44. This enables “any substance” to be put into deep-level land:

> 44 Further provision about the right of use
> (1) The ways in which the right of use may be exercised include—
> (a) drilling, boring, fracturing or otherwise altering deep-level land;
> (b) installing infrastructure in deep-level land;
> (c) keeping, using or removing any infrastructure installed in deep-level land;
> (d) passing any substance through, or putting any substance into, deep-level land or infrastructure installed in deep-level land;
> (e) keeping, using or removing any substance put into deep-level land or into infrastructure installed in deep-level land.

S.44(3) also states that ‘the right of use includes the right to leave deep-level land in a different condition from the condition it was in before an exercise of the right of use (including by leaving any infrastructure or substance in the land)’ (*Infrastructure Act 2015*). As a result, there is no form of restriction regarding the disposal of wastewaters within a well contained in the *Infrastructure Act* 2015. It is the responsibility of the EA to ensure that wastewater is treated as mining waste which may be subject to change in the future. This thought is expressed by PN04:

PN04: *"that’s where a lot of the wastewater injection happens. Um, that’s not supposed to be happening here, um, that’s at the moment but who knows what we might come up with at some point in the future."*

PN04 goes on to suggest that the quantity of wastewater that is produced (section 5.4.2. discussed that this could range between 25%-75%), can affect the operator’s ability to deal with such waste. This is because an operator may only have permission to store a certain amount of wastewater on-site:

PN04: *"what came up at the Cuadrilla enquiry in terms of disposing of waste. If you have got more wastewater impact than you had predicted and you can't get it off the site, you can't store it on the site because you have only got permission for a certain level of storage you can keep it down the well. But the longer you keep it down the well the more concentrated it becomes with contaminants or treatment it will need so that doesn't help you either and it also has implications for seismicity as well so it is a really complicated issue..."*

Where this is the case, the operator may be able to keep fluid within the well, but PN04 notes that this does not necessarily benefit the operator as the wastewater may become more concentrated with contaminants the longer it is kept down the well making it more expensive to treat. Again, this could have knock-on effects for other areas such as well integrity, seismicity, financial costs, and the ability to treat wastewater.

In terms of using wells post-production as areas for storing wastewater for an indefinite period of time, PN06 suggests that reinjection is the cheapest option. This is likely due to the expensive nature of wastewater treatment due to the toxicity of wastewaters:

PN06: *"reinjection is the cheapest option, um, so again under conditions where if we have a struggling economy and we need to expand our economy quickly, to what extent are those regulations going to become more relaxed in order to stimulate industry development?"*

In the following quotation PN14 makes a number of interesting points. Firstly, she talks about re-injection in a negative manner and brings up the issue of well integrity related to the re-injection of wastewaters:

PN14: *"I've had quite a few conversations with the Environment Agency because (short pause) I don't really personally think they should be doing it, I don't really see that as necessary. Um, they've said they will only do it where the well is sort of, um, (short pause) I can't think of the word, like it's got the integrity that wouldn't leak anywhere. Um, they said that, basically they distinguished between flow-back and produced water, um and they wouldn't put flow-back down there. Um, but they have this sort of, stance that if the NORM level is high then they would put it in the ground because they think it would be safer to put it in underground storage than to try and treat it on the surface or to try and transport then treat it which I'm not quite sure if they actually (difficult to hear). So, I personally would like to see proper treatment happen. Um, I think the reason they are reluctant is because it's going to be so expensive to treat the wastewater I think they are intent on trying not to make it less economic (laughs)."*

PN14 identifies the expensive nature of "proper treatment" and the fact that an operator does not want to make the process "less economic". Therefore, in PN14's eyes, underground storage would be the preferred option for operator's as this can be seen as a cheaper and safer method of wastewater disposal (at least in the short-term).

Similarly, PN06 was under the impression that the EA will allow fracked water to be re-injected into a well:

PN06:*"this is something that is quite interesting from a regulatory point of view because the big issues around wastewater reinjection is whether or not you re-inject the fracked water back in to the seam and until quite recently the Environment Agency said no you can't do that (laughs) it was banned, but have recently changed their regulations to allow wastewater reinjection."*

Therefore, the question around whether fracking companies will be able to dispose of wastewaters through the method of re-injection is yet to be answered. This thought is shared by O'Donnell et al. (2018: 326) who state that:

> 'Whilst the Environment Agency (England and Wales) and Scottish Environmental Protection Agency (SEPA) will classify the FP[27] water produced by the hydraulic fracturing process as mining waste, the legality of permitting this to be disposed of through deep injection via disposal wells has yet to be established.'

5.4.5. Other Codes

The codes in this section address issues that are related to wastewater, but do not necessarily fit neatly within the categories that have previously been discussed.

PN05, an academic geologist, questions what the actual plan is for wastewater treatment, suggesting that there is no clear plan:

PN05: *"And then there's the issue of the water that comes back to the surface after fracking, what happens to that? Where does it go? How is it treated? At the moment it is not absolutely clear to me at least what the plan is for that."*

Similarly, PN06 suggests that a lack of research, data and knowledge around the long-term impacts of wastewater re-injection specifically means that a precautionary approach should be taken (i.e. re-injection should not occur under such conditions according to the precautionary principle of environmental law):

[27] The abbreviation *FP* is used by O'Donnell et al. (2018) and refers to both flow-back and produced waters.

PN06: *"there is no good research about what the environmental impacts from what wastewater reinjection would be so that I think is a major concern is whether or not you are putting untreated water back into the ground, what the impacts would be over the longer term and we just don't have data to say reliably what will happen. Um, and I would certainly say that a precautionary approach should be taken under those conditions if you don't know what is going to happen."*

In contrast PN09, from a regulatory body, did not want to go into any great depth with regards to the question asked of him concerning wastewater, simply stating that it will be dealt with "safely", and will be permitted and "rigorously regulated":

PN09: *"Safely (laughs). And I'm not going to say any more than that. It will be very rigorously regulated, um, and they will need to have a permit to discharge anything to surface or groundwater. Um, er, it will have to be of an acceptable standard before it is discharged."*

PN10, an oil and gas consultant, suggests that operator's will have to treat wastewater because of the social and environmental impacts of untreated wastewater disposal:

PN10: *"it depends what's in it. Um, yeah they are going to have to treat aren't they because they can't just chuck it back in a river because people will complain about it because it could potentially cause issues to local wildlife (short pause) (laughs) um, you can't put unsafe water back in the water cycle. It will have to be tested and depending what's in it they will have to treat it (short pause), unless you can sort of recycle it."*

PN10 also very rightly suggests that wastewater disposal or treatment solutions will vary depending on what is contained within such wastewaters. This is one of the reactive features of UHF in that the constituents of wastewater will depend on a multitude of factors which makes planning extremely difficult. Such factors include: the geological matter found within the well; the operator (in terms of how they conduct UHF and what chemical additives they use in the process); and how much flow-back and produced water returns to the surface.

PN16, an oil and gas professional, suggests that oil and gas operations are never perfect, implying that there will be elements of leakage of waste from UHF operations:

PN16: *"(Long pause) if you ask me how I believe it will be treated then that is back to human nature and what I think about humans undertaking these exercises. They are never perfect. Bottom-line. There is no oil platform that doesn't drop a few drops of oil in the sea. Um, we are not perfect in our operations. We can limit the effect and we do our best to limit the effect in general. Um, but, um, there is always an element of leakage or waste from these."*

Similarly, the complexity of wastewater disposal leads PN20 to suggest that such material may be dumped in the ocean:

PN20: *"obviously it is technically possible, er, to dispose of the water, but you have got to get the water to the site of disposal, or you have got to build that site of disposal, er, next to the fracking rig which utterly changes the equation of what people are encountering. Er, and, er, you know the, it wouldn't surprise me to see the line of, we'll drive it to the ocean and dump it in the ocean."*

However, PN17, from a regulatory body, makes an important point that UK industries have many decades of experience of dealing with produced water from a variety of different processes:

PN17: *"one of the key things that people don't understand with water is that there are basically two issues with, with, um, produced water* *from the well. There's what they call flow-back from the, from the hydraulic fracturing process, um, but there is also, you know, and this is well known in the industry and, um (short pause) symptomatic of most oil and gas wells, that there is also water produced from the formations. Um, and, um, the industry has got decades of experience of dealing with water, you know, produced water from wells and that, you know, I don't see that being too much of an issue."*

Nonetheless, PN17 fails to recognise the difficulty in dealing with highly-contaminated produced water and issues around the volume of wastewaters that specialised facilities can deal with, along with the very small number of treatment facilities that are licensed to deal with such produced water. Similarly, the UK actually has only very limited experience of dealing with wastewater emanating from UHF because the process is at a very early stage.

PN19, an anti-fracking campaigner, suggests that operator's will find the cheapest way to deal with wastewaters, rather than the safest way:

PN19: *"I think it is 80% of it that comes back to the surface, what are they going to do with it? A lot of the time they just throw it in pits, they'll throw it into the Sea, they'll do anything they can to get rid of it, and it'll be the cheapest way of getting rid of it that will be utilised, not the most safe, it will be the cheapest and it's not going to be beneficial for anybody to be near the stuff that comes back up."*

5.4.6. <u>Conclusion</u>

Section 5.4. has highlighted the complexities surrounding the management of fracking wastewaters in a UK context drawing upon interview data from several participants. Section 5.4. intentionally split these issues into three distinct sub-sections (wastewater treatment; surface storage and transport; and re-injection and underground storage).

Participants suggested that the proper treatment of wastewater at specialist facilities is an expensive solution also questioning whether such facilities have the capacity and capability of dealing with wastewaters, particularly where NORM's are concerned. The question of treatment is reliant upon a number of factors including: the financial position of each operator; the amount, type and cost of wastewater treatment; and discussions and permitting with the Environmental Regulator.

Treating wastewater at a specialist facility is not only expensive in terms of treatment, but the uncertainty surrounding how much flow-back water may return to the surface could affect transportation plans and costs, as well as the ability to store certain volumes of wastewater on-site (which is subject to permitting). The question of wastewater management then depends largely upon how much wastewater is produced. However, the convoluted legality surrounding re-injection and the uncertainty of wastewater volumes has led to a reactive attitude to wastewater management on behalf of industry and government. To quote PN05 (page 209) "at the moment it is not absolutely clear to me… what the plan is".

5.5. <u>Conclusion to Results Chapter (Water)</u>

Chapter Five has deduced many things with regards to the potential for UHF processes to impact water (specifically water aquifers, water resources and wastewaters) based on interviews with selected key-informants. A summary of the key findings from this chapter is displayed in the Conclusions Chapter (see section 8.1.).

The following chapter (Six) will continue the presentation of results from interviews conducted for this thesis. However, instead of concentrating on water, Chapter Six will consider the four remaining *other* issues addressed in the research. These include the potential for UHF processes in the UK to impact: seismicity; chemical usage; well integrity; and flaring.

Chapter Seven (Analysis) will return to the issues surrounding water discussed in this chapter and integrate such results with the theoretical concepts of ToP and eco-philosophy to provide a unique insight and evaluation of water issues surrounding UHF processes in the UK.

Chapter Six: Results (Other)

6.1. Introduction

Chapter Six is the larger of the two results chapters and contains one more topic than Chapter Five. Specifically, this chapter will address the following deductive categories:

Deductive Category Four: Seismicity
Deductive Category Five: Chemicals
Deductive Category Six: Well Integrity
Deductive Category Seven: Flaring

These results are based upon responses from participants that largely emanate from the questions asked of them concerning each particular topic (see Appendix Seven). However, these categories are not entirely deductive in nature because some issues within the research overlapped[28]. The first category discussed in this chapter, however, is deductive category four (seismicity).

6.2. **Deductive Category Four: Seismicity**

6.2.1. Introduction

Participants responses with regards to seismicity can largely be categorised into five main areas: the effect that pre-existing faults have on seismicity; the effect that re-injecting wastewaters into existing (re-use) or abandoned wells (disposal) has on seismicity; the regulation (particularly the 'traffic-light monitoring' system) in place surrounding seismicity from fracking activities; property damage; and the effect that seismicity from fracking may have on the integrity of wells (existing and abandoned).

[28] For instance, some participants discussed well integrity when talking about seismicity, and vice versa.

So far in the results, each deductive category has been split into three respective sections; the potential positive effect fracking may have on the topic in question; the potential negative effect fracking may have on the topic in question; and other interesting codes that are neutral, or do not fit neatly into either of the other two sections.

This section (Deductive Category Four: Seismicity) however, will take a different format based on the nature of responses from participants. Instead of dividing answers into - potential positive/negative, other – the analysis will take each of the five main areas in sequence. This is because participants often used the five main areas in different lights (i.e. both positive and negative) and, therefore, it is simpler to discuss them in turn, rather than going through each area twice. An obvious example of a topic being used as both a positive and negative argument is the area relating to the re-injection of wastewaters. Some participants, for example, expressed that seismicity is of little concern, unless re-injection is permitted in which case it will be of considerable concern (a negative outlook). In contrast, some participants expressed that seismicity is of little concern and that re-injection is not permitted (a more positive outlook on the effect of seismicity). As a general rule, however, participants had much to say about the relationship between seismicity and UHF, an issue that PN06 suggests there is lots of evidence for:

PN06: *"there's lots of evidence that fracking does cause seismic events."*

This section will now go through each of the main five areas in turn.

6.2.2. Pre-Existing Geological Faults

Several participants explained that seismicity may occur through the activation of fault lines. According to Speight (2013: 154) a geological fault line is:

> ‘a fractured surface of geological strata along which there has been differential movement; a fracture surface in rocks along which movement of rock on one side has occurred relative to rock on the other side.’

Essentially, then, anthropocentrically induced micro-seismic activity from the hydraulic fracturing of a shale formation deep underground may cause a geological fault line to *slip* causing an earthquake of a larger magnitude. Whilst natural earthquakes can cause nearby faults to ‘slip’ triggering an earthquake (Ellsworth, 2013: 3), this can also happen for man-made seismicity. According to Ellsworth (2013: 3), ‘when removed from the source, induced earthquakes typically release stored tectonic stress on pre-existing faults, as do natural earthquakes.’ The potential for fracking to therefore activate a geological fault line can be seen in the quotations in this section. The first quote comes from PN05, an academic geologist:

PN05: *"the only real issue would be whether a company has adequately characterised the faults or fractures in the subsurface and that can be to an extent very difficult to do so even when you do it you may not know exactly what’s going on, um. But in theory at least you should be able to avoid areas where there are obvious potential structural weaknesses that could move, that could cause bigger earthquakes but as I say the UK does not see major seismicity and I think that would be something that is relatively easily monitored in terms of setting micro-seismic monitoring stations around an area and I think they have now put in place guidelines about, um, (short pause) traffic light type signals that shows that if a magnitude of a particular level is detected then the process would have to stop and more monitoring carried out."*

Firstly then, PN05 states that “the only real issue would be whether a company has adequately characterised the faults or fractures in the sub-surface”. This is significant because of the hydraulic fracturing that took place at Preese Hall in 2011. Here, fracking caused a geological fault line to slip causing two significant seismic events of (Richter scale) magnitude 1.5 and 2.3 (Clarke et al. 2014; Green et al. 2012; Wilson et al. 2015). This was allowed to happen due to the absence of legislation (there is now the *Infrastructure Act 2015*) and regulation (traffic-light monitoring and seismic testing are now required, both discussed later in this section).

Secondly, in terms of the quotation from PN05 (above), he mentions “traffic light type signals”, and “micro-seismic monitoring stations” which will now be briefly explained. Firstly, there is a traffic light system in place that is designed to halt hydraulic fracturing operations if seismicity reaches a certain level on the Richter scale. Whilst this is small at 0.5 magnitude (DECC, 2013), the regulations only apply once seismicity has already occurred which again demonstrates the reactive nature of the regulatory approach to fracking control measures. Similarly, micro-seismic monitoring of the local underlying geology is carried out prior to hydraulic fracturing. Whilst this gives operators a better idea of the sub-surface structure, monitoring often occurs after a company has already bought a PEDL license and started working on their land getting it ready for fracking. This begs the question; would the discovery of geological faults prevent an operator from conducting UHF, particularly if they have already heavily invested in such an area? Additionally, this again demonstrates the reactive nature of fracking procedures.

The following quotation from PN13 confirms the relationship between geological faults and the earthquakes that occurred at Preese Hall in 2011:

PN13: *"there's evidence that, um, I would call them tremors not earthquakes, they are very very small, um, effect, and usually as happened at, er, Preese Hall where (short pause) fracture fluid entered an existing fault and then caused it to move. Because what happens is of course if you put water down, down the fault that reduces the friction and so it's more likely to move, um, and that's just basic physics really (laughs). Um, so yes that that, there is that possibility, um, of course and that can be mitigated by proper, um, investigation of fault zones before you start drilling. Where, and of course, there's seismic events are as I say generally speaking apart from that one incredibly small, you wouldn't even know they are happening."*

Using the Preese Hall seismic events in Blackpool in 2011 as an example, PN16 explains how fracking can release energy to create a "seismic shock" or "earthquake":

PN16: *"that is basically what you see when you look at all these reservoirs forming in the, having been formed in the southern North Sea. So, that, the formation of those reservoirs was, is something that happened 50-100 million years ago but the process that sits behind it, African plates pushing into the European plate, it continues. So, the forces are dynamic we do see earthquakes, Market Rasen, not far from here had one. Um, it's the release of the energy that we call a seismic shock or earthquake. Now, by (short pause) by fracturing what is quite a competent rock, shale, um, you can release some of that energy. You will not always release it, it depends whether you are in a slip zone, where you actually have pre-existing fault lines where you weaken the resistance to further slip and that's what happened in the trough of Bowland in the, er, sort of, Blackpool way."*

Firstly, PN16 explains plate tectonics and goes on to say that fracking specifically is targeting a "competent rock" (shale) and, when fracturing, can release the energy stored inside. PN16 notes that energy is not always released, but it will be if conducted in or near a slip zone, where pre-existing fault lines "weaken the resistance to further slip". This corresponds to academic research on the subject, for example, the influential research paper entitled *Injection-Induced Earthquakes* produced by William Ellsworth of the Earthquake Science Centre at the US Geological Survey. Ellsworth (2013: 3) states:

> 'Hydraulic connection between the injection zone and faults in the basement may also favour inducing earthquakes, as the tectonic sheer stress increases with depth… in addition, the larger the fault, the larger the magnitude of earthquakes it can host.'

The second main theme that participants often discussed was the potential impact that the re-injection of wastewaters can have on seismicity.

6.2.3. Re-Injecting Wastewater into Pre-Existing or Abandoned Wells

At the time of submission, fracking in the UK is at the *exploratory* stage as opposed to the *production* stage (see: DBEIS, 2017a). What this means is that there is no fracking wastewater being created from hydraulic fracturing. As a result, it is unknown how wastewater will be disposed of in the UK. It is possible to look at public domain information from the Environmental Regulator (the EA), who suggest that (if fracking wastewaters cannot be reused) 'it must be treated to remove contaminants at a permitted waste treatment facility' and it 'cannot be re-injected into the ground for disposal' (EA, 2017: 2).

However, further research into the Environment Agency's Onshore Oil and Gas Sector Guidance reveals that both flow-back fluid (water that returns to the surface after original drilling) and produced waters (formed through production) may both be re-injected into a well for (further) production purposes (EA, 2016: 44-47). Additionally, whilst flow-back is not permitted for disposal purposes (EA, 2016: 46-47), produced water (with the relevant permit) may be re-injected for disposal purposes where the NORM concentration is above a certain value (EA, 2016: 45). This is because the EA deem re-injection for disposal purposes as the 'best environmental option to minimise the exposure of the public to ionising radiation from the disposal of radioactive waste' (EA, 2016: 45).

In the United States however, the re-injection of wastewater has been used both as a method for re-using fracfluid in the hydraulic fracturing process (depending on the water quality) or as a method for disposing of/storing wastewater (Estrada and Bhamidimarri, 2016). Generally, there are four options when it comes to disposing of wastewaters: treating such water at a wastewater treatment facility and then releasing back into natural hydrological cycles (i.e. rivers, the sea, canals) (Kulander, 2013: 1109); leaving wastewater in on-site surface pits (to evaporate or mixed with water to evaporate, or left to seep underground) (Kulander, 2013: 1109; Rodriguez and Soeder, 2015; White, 2014: 646); land application (such as road spreading) (Hammer et al. 2012: 3); or disposing of wastewater in an underground storage facility (i.e. abandoned oil and gas wells) (Akob et al. 2016).

Participants expressed that whilst hydraulic fracturing does cause seismicity, seismicity is more likely to occur (and to a greater extent) from the re-injection of wastewater. This can be seen in the following quotation from PN07, a Parish Councillor:

PN07: *"I don't think seismicity is the biggest issue here. I mean people have made a big thing out of seismicity, and I don't think it's as major with fracking as its been made out to be. I think the problems that have occurred with seismicity in the States have been through re injection wells. So, it's injecting huge, you know, large* *volumes of liquid into these abandoned wells, at pressure, which has caused the problem."*

Similarly, PN12 notes that if you do not re-inject wastewater then you “have to solve the other problem of what you actually do with it” (see quotation below). This is an important point because re-injection is often seen as a cheaper waste disposal method than treating water at a wastewater treatment facility which can be an expensive option as wastewater can contain a mixture of fracking chemicals, brines and NORM’s:

> “Another challenging aspect of wastewater concerns the "NORMs," or naturally occurring radioactive materials, that it collects from the Earth. Treatment facilities, for their part, have a hard time treating wastewater because it often returns to the surface with radioactive formation materials from deep underground. Those formation materials may include brines, heavy metals, radionuclides, and organisms that make wastewater treatment difficult and expensive” (Abayev, 2017: 283).

PN12 also reiterates the fact that the UK has “complex fractured geology” and that the only UHF to date in the UK (referring again to Preese Hall at Blackpool) resulted in two minor earthquakes and one well failure. Interestingly, despite listing a number of reasons that affect seismicity (from fracking; i.e. re-injection and complex fractured geology) PN12 concludes by stating that seismicity is “not a non-issue but it’s not the main issue”:

PN12: *"if you don’t re-inject it you then have to solve the other problem of what you actually do with it. Canada, in Canada there is strong evidence that almost all, pretty much all of the earthquakes they have been having in Alberta have been the result of fracking. It is an area that was not previously prone to earthquakes. Um, and in terms of this country it is difficult to say we are not a major earthquake zone, er, we are not Italy, er, but we do have complex* *fractured geology, we do actually have a lot of minor earth tremors in this country that most people don't notice and the record is so far one high-pressured frack, one, um two minor earth tremors and one well-failure. So, 100% record so far. And again, it's um, you know fracking, you know fracking is doing something serious when the ground starts to shake, er, but again in terms of an indirect link to harm to people where there's so many more direct links to harm to people than earth tremors. So, it's not a non-issue but it's not the main issue."*

In the United States, re-injection has been used as a common waste disposal technique[29] since UHF began in the late 20th Century (Rodriguez and Soeder, 2015: 22). Re-injection has been directly attributed to an increase in seismicity by many research papers (Davies, et al. 2013; Ellsworth, et al. 2015; Ellsworth et al. 2016; Kim, 2013) and, as a result, it is now commonly accepted that the re-injection of wastewater is directly linked to seismic activity and at greater levels than the act of hydraulic fracturing itself. However, there is a more philosophical debate to be had surrounding the intentional creation of seismic activity (whether that be from UHF itself, or from the reinjection of wastewaters). Does it matter that humans are actively encouraging earthquakes through such industrial processes?

Whilst earthquakes cause massive loss of life globally, the largest earthquakes recorded as a result of fracking are only 5.6 on the Richter scale (Ellsworth, et al. 2015), and this occurred from the re-injection of wastewater in the United States. Although 5.6 is a

[29] Whilst this has been the case for the longevity of UHF in the United States, Rodriguez and Soeder (2015: 22) explain that there has been a shift in terms of how wastewater is dealt with in the US with companies increasingly using methods of recycling and re-using wastewaters. With regards to re-cycling, Lutz et al. (2013: 655) explain that re-cycling of wastewater is becoming more common, particularly in Pennsylvania where rates have increased from 13% to 56%.

considerable seismic event, it is generally not enough to cause any serious threat to human life. On the other hand, from an economic perspective, an earthquake of 5.6 magnitude is certainly enough to test the structural foundations of buildings, particularly in non-earthquake prone areas where buildings have not been designed to cope with seismic activity. The structural integrity of buildings certainly carries a threat to human life, and, as PN19 points out, the United Kingdom is not an earthquake prone country, and could therefore be affected by an increase in significant seismic activity:

PN19: *"earthquakes, whatever they are on the Richter scale in this country will affect the buildings locally because the foundations of the buildings are not structurally sound enough to cope with the vibrations because we are not an earthquake prone country. We have not built the buildings to cope with any earthquakes of any magnitude because we don't really get them..."*

Again, from an economic point of view, seismicity could result in major economic loss in terms of building repairs and insurance claims. As Ellsworth, et al. (2015: 625) note:

> 'the most probable risks in areas of increased seismicity include life-threatening injuries caused by falling objects and economic loss from damage to structures with low capacity to absorb moderate earthquake shaking.'

Alongside the potential for UHF to cause seismic activity through the re-injection of wastewater, several participants referred to the traffic-light monitoring system, a regulatory control measure for fracking in the UK.

6.2.4. Regulation and the Traffic-Light System

Several participants acknowledged that there was a traffic-light system in place to regulate the seismicity that occurs from UHF.

Often, this was said in a positive way to suggest that the participant thought this particular regulatory system to be appropriate (even if reactive):

PN05: “*I think they have now put in place guidelines about, um, (short pause) traffic light type signals that shows that if a magnitude of a particular level is detected then the process would have to stop and more monitoring carried out so."*

PN07: *"Low-level seismicity? (Long pause), they’ve got the traffic light system which is a reactive one, um, rather than a proactive one. So, it only tells you when somethings happened. And it is set, it is set very low (short pause), but I don’t think seismicity is the biggest issue here. I mean people have made a big thing out of seismicity, and I don’t think it’s as major with fracking as its been made out to be.”*

The DECC introduced a traffic-light monitoring (TLM) system in 2012 (post-Preese Hall) as part of a new set of requirements, controls, permissions and risk assessments for UHF overseen by the Health and Safety Executive (Hammond et al. 2015: 2766). The TLM system essentially has three measures; Green, Amber and Red. Operators are permitted to conduct UHF (subject to all other legislative and regulatory formalities) and, if no seismicity occurs then fluid ‘injection proceeds as planned’ (DBEIS, 2017. See: Appendix Twelve). Similarly, if seismicity is detected between 0.0-0.5 on the Richter Scale, ‘injection proceeds with caution, (but) possibly at reduced rates’ (DBEIS, 2017. See: Appendix Twelve). However, if seismicity occurs of Richter Scale Magnitude 0.5 or higher, ‘injection is suspended immediately’ (DBEIS, 2017. See: Appendix Twelve).

Whilst PN09, from a regulatory body, acknowledges that the events at Preese Hall in Blackpool did lead to minor earth tremors, they were very small. As a result of this and the regulation in place to protect against seismic activity, PN09 suggests that as long as fracking is done properly and regulated properly, seismicity should not be a risk:

PN09*: "the actual seismic events that took place in, er, Lancashire, er (short pause) I mean people talk about seismic events and earthquakes and technically that's absolutely correct but they were very very very minor earth tremors. We are talking about the sort of experience of a lorry driving past your house type of thing. Um, not buildings crashing down. Um, so I think it is important to get that in proportion. The actual risk from seismic events from fracking, material, substantive seismic events, very very small I would have thought um, as long as it is done properly and regulated properly."*

The TLM system for seismicity and fracking has been set at a very low level as 0.5 on the Richter scale cannot be felt by humans, it can only be detected by advanced seismic apparatus. As a result of this, many have claimed that the TLM system is set unrealistically low, insinuating that conducting UHF at such low seismic levels may be unachievable (Browitt and Walker, 2014: 3; Task Force on Shale Gas, 2015: 12). Nonetheless, there is a critical point to bring up here that presents a major flaw in the TLM system which arises from the events that occurred at Preese Hall in 2011. Two significant seismic events were recorded that have been directly attributed to the fracking operations conducted at Preese Hall (Green et al. 2012). However, importantly, these events did not occur until 10 hours after the fracking had taken place (Green et al. 2012: 1). Such a delay shows the complexity of the underlying geology of that part of the world and suggests that regulation may not be successful in preventing massive seismic events from occurring. This is a crucial flaw and, again, underlines the extremely reactive nature of the TLM system.

As well as debates surrounding the regulation of UHF activities in the UK, some participants alluded to the negative effect that seismic movement could have on property.

6.2.5. Property Damage

Three participants expressed the idea that they thought UHF may have a negative impact on property (in terms of damage to property and other infrastructure) as a result of seismic activity stemming from UHF operations. Whilst there is certainly evidence of property damage from the seismic events that occurred at Preese Hall in 2011 (Green et al. 2012: 12), there is also evidence of property damage in the United States (Logan, 2016; Quigley, 2016: 5). To re-iterate a quotation from PN19, an anti-fracking campaigner, discussed earlier, property damage may occur in the UK from UHF activities because “the foundations of the buildings are not structurally sound enough to cope”:

PN19: *"earthquakes, whatever they are on the Richter scale in this country will affect the buildings locally because the foundations of the buildings are not structurally sound enough to cope with the vibrations because we are not an earthquake prone country. We have not built the buildings to cope with any earthquakes of any magnitude because we don’t really get them..."*

PN19 is incorrect in stating that the UK does not “really” endure any earthquakes. On the contrary, the UK withstands many low-level earthquakes every year. In fact, the BGS keeps a database of all the earthquakes in the UK, their locations and their respective magnitudes (BGS, 2017b). However, what the researcher believes PN19 is trying to say, is that the UK rarely sustains earthquakes of a great magnitude compared with other areas of the globe. In fact, the largest earthquake detected in the UK (since records began), is 6.1

(offshore) with only a handful over 5.0 on the Richter scale onshore according to the BGS (2017c).

An important point was raised in relation to the potential damage to property caused by fracking-induced seismicity by PN12, an anti-fracking campaigner, who suggested that, whilst damage may occur, it would be very difficult to put a monetary or philosophical value on the effect that seismic activity has on property damage:

PN12: *"Yeah I mean I imagine the damage to property would be, um, small and long-term if you are having regular earth tremors, buildings that might last 30 years might last 20 years and so on, it would be difficult to put a value on that."*

Additionally, PN07, a Parish Councillor, alluded to the health and safety concerns regarding property damage and the threat that such damage could bring to human life:

PN07: *"if there's structural damage and a chimney falls on your head then it's pretty bad news isn't it (laughs). No, we had one what was it, 3.5 or 4? That one we had a few years ago that was centred in Market Rasen? Um, that practically shook me out of my bed in (omitted – confidentiality). So, I mean there was a lot of structural damage in Gainsborough."*

Finally, besides property damage, PN06 suggests that seismicity generated from UHF operations may cause further damage to other types of property and infrastructure:

PN06: *"there are always additional costs; cracks in roads, cracks in buildings you know, we are not talking about having whole buildings collapse you know, but it's really a question of infrastructure resilience and maintenance and those are all partly dependant on the* *region that is fracked. So if it's closer to an urban centre the impact may be greater."*

Interestingly, PN06 suggests here that the cumulative impact of seismic-related damage may be greater when fracking takes place in closer proximity to urban areas where, essentially, there is a greater quantity of buildings and infrastructure than in more rural or less populated areas.

Although fracking will certainly have an effect on seismicity and may potentially have an effect on the structural integrity of property, the final part of this section (Deductive Category Four: Seismicity) is focussed on the relationship between seismicity and well integrity. Although Deductive Category Six will also consider issues of well integrity, the following part looks exclusively at well integrity issues related to seismicity.

6.2.6. Seismicity and Well Integrity

Two main issues were brought up by participants with regard to the relationship between well integrity and seismicity; the effect that seismicity from UHF may have on the integrity of the well that produced the seismic activity; and the effect that seismicity may have on the integrity of other wells (in operation or abandoned). With regards to the first point (the integrity of the original well), PN05 explains how the integrity was affected by induced seismicity at Preese Hall in 2011:

PN05: *"research… shows that if you look at conventional oil and gas wells then ok, the older the wells are the different technology was in place may be they were not as structurally robust so they can leak over longer timescales but even with the best modern technology, um, and indeed within, um, Cuadrilla's test site it is clear that when they induced, um, the seismicity they also affected the integrity of* *their own well so again, there can be impacts from the process itself on their own wells during the very early lifetime of the well..."*

Additionally, PN18 suggests that the integrity of the well is very important:

PN18: *"people who talk of earthquakes are sort of over-egging it a bit, but I think in many respects whatever you decide to call these is neither here nor there, the point remains that in any event they are supposed to be ensuring the integrity of the well. So, if they have any event like that then we would expect them to be running tests, you know, pressure tests again to make sure that if there has been any, er, any issue like that, that they are content that the well has not been damaged in any way."*

PN18 relates the debate of seismicity and well integrity back to regulation. In any event, the operator is “supposed to be ensuring the integrity of the well” regardless of whether or not operations are resulting in seismic activity. The integrity of the well is scrutinised (during well design and instillation) by the independent well examiner (the HSE) and the operator is expected to be running pressure tests to ensure that the fracturing that they have undertaken has not caused the well to have “been damaged in any way”. This inspection of wells and insurance of well integrity is not specific to UHF but is common practice within oil and gas activities in the UK both onshore and offshore (UKOOG, 2013c: 25-27).

Again, however, it could be viewed that running pressure tests to ensure well integrity, whilst a vital and necessary component to oil and gas development, is still a reactive approach to developing hydrocarbons. For example, a pressure test may be run that results in an operator finding out that the integrity of the well has been compromised in some way. Whilst such information is vital in ensuring no further fluid injection takes place, it may not prevent environmental contamination if well failure has occurred.

The second impact that seismicity may have on well integrity involves the possible effects on nearby wells, or wells in close proximity to where seismicity occurs (seismicity may not always be in the immediate vicinity of the well that caused the seismicity, as in the case of Preese Hall in Blackpool. See: Clarke et al. (2014), for further details). As PN14 explains:

PN14: *"they are very minor aren't they and I think yeah, if there is no risk to human health or property damage, um, then they are on the same scale as what would naturally occur anyway so yeah, I think that's fine. But I think the risk comes from adjacent wells and are you going to affect the well integrity of any other wells and any other disposal wells."*

This comment from PN14 presents a very important point with regards to fracking and seismicity. If it is appreciated that seismicity is a risk to the integrity of a well, and the integrity of the well is extremely important in preventing environmental contamination, then earthquakes are not only a risk for the particular well (disposal or not), but also for other wells in the vicinity. Academic literature surrounding fracking and seismicity suggests that seismicity often occurs in close proximity to where fracturing occurs, but can happen at greater distances (for example if a nearby fault is triggered). For example, Holland (2011: 1) found that the majority of detected earth tremors (43 within a 24-hour period in Garvin County, Oklahoma on 18th January 2011) occurred within 3.5 kilometres of an 'active hydraulic fracturing project' near Elmore City. Whilst this suggests that seismicity does occur close to hydraulic fracturing sites (or re-injection sites), it also suggests that nearby wells have the potential to be affected by induced-seismicity. This is a major consideration for well integrity, and more research needs to be conducted to measure the distance of seismic activity to UHF wells.

Although this is important, it must be noted that it is very difficult to distinguish between naturally occurring seismic activity, and induced seismicity (Ellsworth, 2013). Therefore, it would be unwise to attribute felt earthquakes to nearby UHF wells, and the greater the distance the more difficult that would seemingly be. As Ellsworth (2013: 3) states:

> 'At present, with the use of seismological methods, it is not possible to discriminate between man-made and natural tectonic earthquakes. Induced earthquakes sometimes occur at the source of the stress or pressure perturbation; at other times, these events take place deep below and kilometres away from the source. When removed from the source, induced earthquakes typically release stored tectonic stress on pre-existing faults, as do natural earthquakes. Sometimes induced events occur shortly after the industrial activity begins, but in other cases they happen long after it has been under way or even ceased.'

This final sentence is what distinguishes natural earthquakes from man-made ones (although the original source of an earthquake is always debateable). As McGarr et al. (2015: 830) describe: 'Natural seismicity is usually assumed to be independent of time in assessing its hazard. Seismicity induced by fluid injection, in contrast, varies with time, often because of changes in injection rate.'

6.2.7. Conclusion

This section has focussed exclusively on seismicity related to fracking and the responses provided by participants with regards to the question asked of them regarding seismicity (see Appendix Seven). In order to separate participant responses into digestible categories, this results section has categorised responses into five parts: pre-existing geological faults; re-injecting wastewater into pre-existing or abandoned wells; regulation and the “traffic-light” system; property damage; and well integrity.

Firstly, section 6.2.2. focussed on the effect that UHF might have on triggering pre-existing geological faults. Participant responses (particular those from PN05 – an academic geologist) were aligned with academic research (Davies et al. 2013) both of which suggested earthquakes may be triggered by the activation of pre-existing geological fault lines. Whilst the significance of seismic monitoring and the regulatory TLM system which are designed to both understand underlying geological structures, and to stop UHF occurring if seismicity reaches a Richter scale magnitude of 0.5 or more, many participants related fault *slips* to the activities at Preese Hall in 2011 which caused two earthquakes of 1.5 and 2.3 Richter scale magnitude (Clarke et al. 2014; Green et al. 2012). These earthquakes have been attributed to UHF, and in particular, to geological faults (Wilson et al. 2015). Participants were very aware of this.

Secondly, section 6.2.3. concentrated on the re-injection of wastewaters into abandoned wells. Although it is currently unknown how much wastewater will be dealt with in the UK, generally, there are four options when it comes to disposing of wastewaters (methods that have been employed in the United States and elsewhere): treating such water at a wastewater treatment facility and then releasing back into natural hydrological cycles; leaving wastewater in on-site surface pits; land application (such as road spreading); or disposing of wastewater in an underground storage facility (i.e. abandoned oil and gas wells).

Participants largely expressed that UHF does cause seismicity, but that the re-injection of wastewater is a greater concern (in terms of earthquakes, as opposed to induced earthquakes from the actual act of hydraulic fracturing itself). A small number of participants stated that higher levels of seismicity, whilst unlikely to be life-threatening, could have ramifications for the structural integrity of buildings. Seen as re-injection is commonly associated with higher levels of seismic activity than the act of hydraulic fracturing itself (Ellsworth, 2013), re-injection is certainly a concern for structural integrity.

Section 6.2.4. considered seismic regulation and the TLM system. Whilst it was noted that such a system is critical in halting UHF operations that cause seismic activity, and that the threshold for ceasing operations is set a very low level of Richter scale magnitude 0.5 and above, such a system can be seen as a very reactive process (i.e. earthquakes must occur for operations to cease). This is important because the earthquakes generated by Preese Hall in 2011 occurred several hours after hydraulic fracturing took place meaning that the traffic light system would have only been implemented after the earthquakes of 1.5 and 2.3 had already occurred.

Following on from this, the fourth section (6.2.5.) focussed solely on the impact that seismic activity could have on property and infrastructure. Three participants mentioned property damage in relation to seismicity, and there is evidence to suggest that property damage has occurred in the United States (Logan, 2016). However, the extent of property damage will ultimately depend on the number of UHF operations that occur in the UK, the number of wells that are drilled, and whether wastewater is re-injected into wells (because of the relationship between re-injection and seismicity).

Finally, section 6.2.6. was directly concerned with the relationship between well integrity and seismic activity. This was divided into well integrity relating to the original well that caused seismicity, and then other nearby wells that could potentially also be negatively affected by seismicity that occurs from a different well.

It is important to note in the conclusion to this section that UHF is not the only industrial practice that causes seismic activity. Other energy sources such as coal and geothermal energy are associated with higher levels of seismicity than UHF (Moss et al. 2013: 37-38). However, the concern with seismicity and UHF is not necessarily with the magnitude of induced-earthquakes, but how such earthquakes could negatively affect the integrity of well casings and the ability of such casings to provide adequate protection to prevent fluids from contaminating groundwaters and the underlying geology more broadly. The significance of well integrity will be discussed again in Deductive Category Six (Well Integrity).

Although the concerns surrounding seismicity are mostly attributed to property damage and well integrity, as a whole, participants thought seismicity was not the main priority with regards to the potential for UHF to cause environmental harm.

6.3. **<u>Deductive Category Five: Chemicals</u>**

6.3.1. <u>Introduction</u>

This section will be split into two. Firstly, participant responses will be presented that directly state the name of a chemical (or a number of chemicals) that they believe will be used in UHF. Further, such responses will be sub-divided into smaller categories such as quotations directly related to a particular chemical that was mentioned multiple times (for example, Hydrochloric Acid).

Secondly, participant responses will be presented that talk more broadly about chemicals and their potential effects, for example, on public health or issues relating to commercial confidentiality. The first section (6.3.2.), however, will concentrate on specific chemicals expected to be used in UHF processes.

6.3.2. <u>Specific Chemicals</u>

6.3.2.1. *Hydrochloric acid*

The main chemical that participants referred to was Hydrochloric Acid. The EA class Hydrochloric Acid as a substance that is non-hazardous to groundwater, so long as concentrations are kept at a low-level (Jacobsen et al. 2015: 30). In order to understand Hydrochloric Acid and the potential impacts that it could have on the Environment and public health, it is imperative to understand it's properties. According to Shelley (2011: 15) Hydrochloric Acid is a 'strong acid; severely corrosive, (and a) strong irritant to (the) eyes, skin (and) lungs.' Hydrochloric Acid is formed when Hydrogen Chloride (a gas) contacts water. According to Bull (2007: 2):

> 'Acute ingestion of hydrochloric acid may cause burns to the lips, mouth, throat, oesophagus and stomach, dysphagia, nausea and vomiting. Skin exposure to low concentrations of hydrogen chloride gas or hydrochloric acid causes erythema and inflammation of the skin whereas high concentrations can cause severe chemical burns to the skin and mucous membranes.'

It is arguable that there are three main risks concerning hydrochloric acid, fracking and public health in the UK. The first concerns transportation and storage. If a truck carrying Hydrochloric Acid (even in concentrated form) spills, the corrosive nature of Hydrochloric Acid presents a risk to public health at the location of the spill (either on-site or off-site) depending upon concentration and quantity. Such spills have occurred in the United States (Wiseman, 2011: 9). Secondly, the corrosive nature of Hydrochloric Acid could affect the steel and cement casings of the well compromising well integrity, even if only over a long-time frame (Jackson et al. 2014: 337-338). Finally, exposure of Hydrochloric Acid to groundwater, surface water, the air or other environments could have a negative effect on human health and the health of other species and organisms because of corrosive and irritant properties.

It is likely that Hydrochloric Acid will be used in concentrated form for fracking operations in the UK, but the percentage of concentrate will vary from site to site (however, it is most commonly used at a concentration of around 15%, see: Stuart (2012: 11). However, according to Stuart et al. (2014: 18), Hydrochloric Acid is anticipated to make up only 0.123% of hydraulic fracturing fluid. This is used to dissolve minerals and initiate cracks in the shale rock. Currently, it is unknown what concentrations of Hydrochloric Acid will be used for the purposes of UHF in the UK but it is likely that percentages will vary depending upon the operator. Although 0.123% appears a very low percentage of Hydrochloric Acid to be used in fracfluid, this could still be a large volume of corrosive liquid if, for example, a fracturing process were to use 5 million gallons of fluid. Based on 5 million gallons, 0.123% equates to approximately 27,958,466 millilitres (or c.27,958.47 litres). c.28,000 litres is therefore a much larger volume of liquid that portrays different emotions to a low percentage of 0.123% of total fracturing fluid.

In terms of the chemical composition of fracfluid, PN04 states that many planning applications now list what substances are expected to be used in fracking operations, but do not necessarily give the chemical compositions of the product. Although, companies and the industry state that chemicals are often common household products, she uses the term Hydrochloric Acid in a negative way saying that “companies are talking about using Hydrochloric Acid”:

PN04: *"Well a lot of them now, a lot of the planning applications list the substances although that’s not necessarily that useful because they are not necessarily giving chemical compositions of the product. The companies and the industry say these are common household* *chemicals, um, but actually even in conventional wells, um, companies are talking about using Hydrochloric Acid."*

PN05 points out that chemical usage will depend on licenses, permits, technology and underlying geology. With regards to geology, he explains that Hydrochloric Acid usage will depend on the mineral content of the shale rock the operator is intending to exploit. He uses the example that, if shale contains more limestone, more Hydrochloric Acid may be used to try and dissolve the limestone to create more space through which the hydrocarbons can flow (i.e. making strata more permeable). Essentially, the materials an operator uses will depend on which substances work best to keep fractures open for as long as possible to produce as much hydrocarbon from the well:

PN05: *"it does depend on the company and the licenses and permits and the technology that they have. The geology will play a role, um, so shale actually varies quite a lot people have this idea that shale is very similar but actually it does vary in terms of the minerals it contains so for example if your shale has more limestone in it, then, um, a company would potentially be using more hydrochloric acid, um, to try and dissolve that limestone and to try and to basically make more space in the rock through which hydrocarbons can flow. Um, er, (short pause) the, there are various sort of conditions that may affect how it behaves after it is fractured so some shales are more brittle than others some are more ductile so again you may need to inject different materials to adequately keep fractures open or to keep fluids flowing, um, and, er (short pause) also as you can quite readily guess some microbial growths developing within the subsurface and those will vary depending on the chemistry of the shale itself and again that can vary so, um, the biocides or the sort of, um, biological inhibitors that you get being injected will vary from site to site."*

Although PN17 begins the following quote by stating that the EA will not allow substances to be used that are hazardous to groundwater, he goes on to say that Hydrochloric Acid may be used to “clean up the well” as part of well completion processes. This appears to be a different usage of Hydrochloric Acid to the usage expected by other participants, and the usage outlined by Stuart et al. (2014: 18), to initiate ‘cracks in the shale rock’:

PN17: *"the Environment Agency as part of their permitting will not allow substances to be used that are hazardous to groundwater. So, whatever substance is used as part of hydraulic fracturing fluid can’t be a risk to groundwater because the Environment Agency won’t allow that (laughs). Um, I suppose the other part of the question that I can explain is not just about hydraulic fracturing fluids there will be other fluids used in the construction and operation of the well. So, like (omitted – confidentiality) said, there will be, um, woods used as part of the drilling process that are, um, basically water based or oil based and contain thermites to increase the weight. There may well be Hydrochloric Acid used to clean up the well as part of the, um, well completion, er, which is diluted..."*

Finally, PN18 notes that the properties of Hydrochloric Acid may change during its usage in UHF operations to create a new chemical compound:

PN18: *"it’s likely to be used up I mean it won’t exist as Hydrochloric Acid in perpetuity because once it’s done its job it’s then, you know, it’s created a new chemical compound and it’s just achieved its job which is basically to clean stuff up."*

Therefore, the uses of Hydrochloric Acid are likely to vary from site to site. The concentration of the substance will also vary depending on the operator and the underlying geology. It is likely, however, that Hydrochloric Acid will be used in some form within UHF processes and, regardless of concentration, this still presents a risk to humans and ecological health in terms of the handling, storing and transportation of the substance, as well as risks associated with where the fluid ends up (underground) after it is used in UHF processes.

6.3.2.2. *Biocides*

Biocides are different from Hydrochloric Acid and are used within UHF operations for a different purpose. Essentially, biocides are used to prevent the growth of bacteria which can lead to the production of ‘corrosive and toxic by-products’ (Stuart et al. 2014: 18). Glutaraldehyde biocide (used by Cuadrilla Resources at Preese Hall in 2011) is a common form of biocide used in fracturing fluids as it helps to prevent the build-up of bacteria which can erode pipes (Al-Bajalan, 2015: 3). PN06, sums up the purpose of using chemicals in UHF operations, particularly biocides, in terms of preventing growths within the wellbore:

PN06: *"it’s a mixture of things like biocides, non, surfactants, um (short pause) and most of it is around stopping things growing in your wellbore which is wet a lot of the time, um, and other things around (short pause) oh I don’t know, things that stop your sands from sticking..."*

PN07, a Parish Councillor, when stating the constituents of fracking fluid, notes how biocides serve an additional function of preventing “the production of hydrogen sulphide”:

PN07: *"What they will argue is that the majority of it is water, um, 99% or something is water, and they say 1% is, are the chemicals. Um, but 1% of 5 million gallons is quite a lot of chemicals which will be stored, which will be transported in concentrated form and they’ll be mixed on site. So, you’ve got, you’ll have water which will be* *piped or transported in. Then you need a lot of salt, um, as a proppant, sorry, a lot of salt, sand, it's sand that is the proppant and they'll have to bring that in. Because they are using salt with brine, with brine water, they need corrosion inhibitors. They need biocides to prevent the production of hydrogen sulphide, which always happens when they drill wells like that and, a) it's toxic and, b) it stinks."*

Bergmann et al. (2014: 7) state that biocides prevent 'bacterial growth, biofilm formation and formation of hydrogen sulphide by sulphate-reducing bacteria.' Therefore, whilst biocides are needed to protect wells from bacterial growth, they may produce additional negative consequences in the form of risks to public health in the airborne exposure to a toxic substance, but also socially in the form of a gas that is not pleasant to smell.

PN13 confirms the reasoning behind the use of biocides in the following quotation when stating that "they'll use a biocide to stop the pipe furring up with bacteria and microorganisms and algae and stuff like that":

PN13: *"Fracking fluid is about, er, 90% water. It's also then about 9% sand which is called the proppant which when you've fractured keeps the fractures open. You then have the remaining 1% which is chemicals. And some of those chemicals are the sorts of things you might find in your garden shed or even in your kitchen. So, for example, they'll use a biocide to stop the pipe furring up with bacteria and microorganisms and algae and stuff like that. So, um, so for example, you will find biocides in many household products or garden products."*

Therefore, biocides are a necessary constituent of fracking fluid, and are among the most common chemical additives used for UHF in the United States (Kahrilas et al. 2015; Lipus, 2017: 5). Although biocides are commonly used in many industries (for example, food preservation and water treatment) for different purposes (such as disinfection, sterilisation and preservation), their properties and effects are very difficult to predict and control in UHF operations (Kahrilas et al. 2015). According to Kahrilas et al. (2015: 16):

> 'Bacteria may cause bioclogging and inhibit gas extraction, produce toxic hydrogen sulfide, and induce corrosion leading to downhole equipment failure. The use of biocides such as glutaraldehyde and quaternary ammonium compounds has spurred a public concern and debate among regulators regarding the impact of inadvertent releases into the environment on ecosystem and human health.'

As a result, the risks concerning biocides are very similar to the risks concerning Hydrochloric Acid. These include: risks to human and ecosystem health if exposed to biocides; risks in handling, storing and transporting the substance; and uncertainties around what will happen to biocides underground (i.e. how the properties may change and whether this will affect piping or well casing in terms of degradation leading to future well failure).

6.3.2.3. *Surfactants and Polyacrylamide*

Surfactants, are often a component of hydraulic fracturing fluids as they act as a friction-reducer or are added to other friction reducer compounds to aide friction-reduction performance (Bolanos Ellis, 2015: 28). Reducing friction is important during the production of hydrocarbons from UHF processes because it enables greater pressure, resulting in larger fractures that stay open for longer (and therefore, making the process more efficient and economic). PN13, a consultant geologist, explains that surfactants are often found in common household items such as washing up liquid and that, as long as large quantities are not used, "it's perfectly safe or relatively safe":

PN13: *"Surfactants which is soap, again, keeping things clean. You are probably more likely to come into contact with a surfactant when you're, um, doing the washing up, you're going to get more exposure that way (short pause). Um, other things, er they use (difficult to hear name) gum which is like a gelling agent which you get in chewing gum. So, most of these things aren't actually particularly, like everything, um, if it's not in a huge quantity it's perfectly safe or relatively safe. I mean, we are exposed to so many chemicals these days, the likelihood of you being exposed to a fracking chemical is incredibly low unless you are actually on site handling the stuff with your bare hands."*

PN18 confirms that Polyacrylamide acts as a free-flow agent that stops particles sticking together:

PN18: *"Polyacrylamide is, um, a free-flow agent. I mean that's used, it's a fairly common compound, that'll be to stop, um, the particles sticking when they are using proppant to go into the fractures."*

Polyacrylamide is regularly used in UHF operations as a friction reducer because there is a great annual decline in the production rates of oil and gas from such UHF wells[30]. According to Murray and King (2012: 435) production rates decrease by 60%-90% annually. By decreasing friction, Polyacrylamide increases pressure creating greater fractures that remain open for longer.

[30] Oil or gas recovery is most fruitful (in terms of volume) when shale is first fractured because this is when the induced fissures are at their longest and widest. Over time, geologic pressure closes these fissures resulting in a decreasing flow rate. Friction reducers such as polyacrylamide are used in order to reduce pressure-loss (Harrison et al. 2014: 5). Pressure is extremely important in inducing fissures in shale rock and in keeping them open because of the impermeable characteristics of shale, and the depth of shale in the UK (depth varies in different locations but usually exists at c.3 kilometres).

Surfactants are very similar to Polyacrylamide as they can be used as a friction-reducer. Xu and Fu (2012) denote that proper application of a surfactant can enhance the initial production rates of an UHF well and help to sustain long-term production by reducing formation damage whilst increasing permeability. Surfactants are common household chemicals (often found within washing up liquids, for example) but can still cause human health issues upon exposure (Shelley, 2011: 15). Therefore, they present a risk to human health when used within fracking fluids.

6.3.2.4. *Conclusion*

The chemicals used in fracking are classed as non-hazardous by the EA, which can be seen in the following quotation from PN14:

PN14: *"at the moment the only things being used are polyacrylamide which I think is commonly found in sort of, face creams and things. Er, hydrochloric acid, I think they can use certain biocides, um, but yeah everything has to be pre-approved by the Environment Agency. No hazardous substances can be used so that's already designated."*

PN06 also suggests that chemicals used are fairly common, used in dilute quantities, and are the kind of household chemicals that one might find under the kitchen sink:

PN06: *"it is usually the types of stuff that you would find under your kitchen sink which I thought was quite a good way of explaining it. Er, you know it's not massively new or particularly sort of, novel chemicals it's just a question of, yeah, you wouldn't want to drink them but again they are used in fairly dilute quantities compared to the volume of water that is produced..."*

The most common chemicals cited by participants were Hydrochloric Acid, Biocides and Surfactants. Whilst these chemicals make up only a very small proportion of the overall composition of fracking fluid (this will vary from site to site, but is generally less than 1%), they still present a risk to humans and the environment. Surface spills and accidents present risks to surface water and groundwater, whilst corrosive elements present a risk to well integrity and human health if such elements come into contact with humans or corrode well casings or piping.

It is currently difficult to determine exactly which chemicals will be used in fracking fluids and in what concentrations, because UHF is at an exploratory stage of development in the UK rather than a production stage which requires chemicals to be used during drilling processes. Therefore, whilst it is important to discuss the potential impacts (social, environmental, economic and health-related) of chemicals used within UHF processes, it is impossible to conclude what the potential effects will be. There are, however, obvious (social, public health and ecological) risks associated with handling, transporting and storing chemicals, as well as risks related to the effect that such chemicals might have on well integrity and sub-surface ecological health.

6.3.3. Issues with Chemicals

Participants were clear that there are many debates around chemical usage in UHF processes. This section (6.3.3.) will discuss four of the main concerns raised by participants which included: the *trial and error* nature of chemical usage; risks associated with transporting chemicals to and from fracking sites; the impact of chemicals on public health; and issues surrounding commercial confidentiality.

6.3.3.1. *Trial and Error*

The development of the horizontal hydraulic fracturing of shale rock by the Mitchell Brothers in the United States was a process of trial and error where thousands of wells were drilled before the procedure was successfully put into production in the 1990's (Ragheb, 2017: 7). Because the properties and depth of shale can vary considerably in different areas of the world (and seismic testing can only reveal so much), all UHF efforts have some degree of trial and error, particularly in terms of the chemical composition of fracfluids needed to successfully force cracks in shale rock, and to keep those cracks open for as long as possible. PN05, an academic geologist, confirms this trial and error nature:

PN05: *"it's unknown at the moment whether let's say the North Yorkshire shale target would behave in the same way as the Lancashire target that Cuadrilla fracked. It's essentially the same age but it may not be the same composition so, um, again there's probably an element of trial and error, um, but the companies will have characterised the geology as fully as they think they need to then make those judgements accordingly."*

As well as trial and error, PN05 uses the term "judgements" in order to describe how a company may react to their characterisation of the underlying geology in terms of how they may proceed with UHF (including which chemicals may be most relevant). This suggests that UHF is not an exact science. Operators must be reactive and flexible, adapting to the needs of the particular location in order to produce the largest volumes of gas possible. Such a trial and error approach to UHF operations reaffirms the naturally reactive nature of the industry.

6.3.3.2. *Chemical Transportation*

The volume of truck movements will vary from site to site (see section 5.2.3.1.). Although volume will inevitably vary, it is undeniable that many hundreds or thousands of trucks will be used to facilitate UHF process at every site. Such truck movements present risks due to either mismanagement or human error. For example, Burton Jr. et al. (2014: 1683-1684) denotes the estimated frequency of truck accidents and the potential concerns that such accidents may bring to the environment (specifically surface waters and groundwater):

> ‘Chemical and wastewater transport vehicles can potentially be involved in traffic accidents, and it is estimated that a 30- ton tank truck will have an accident every 333, 000 kilometres. Although this does not necessarily mean that chemical emissions will occur at every site, the potential for release into the environment remains. Moreover, truck accidents that occur on roads could result in chemicals being spilled on unpaved areas and draining into surface water and groundwater.’

Despite such concerns, operators may take steps to mitigate the risks concerned with transporting chemicals by the production of Traffic Management Plans (TMP’s). These are often tailored to a specific UHF site and include instructions for: abnormal loads; parking; unloading and turning of heavily goods vehicle’s (HGV’s); access to public highways; and site security (Third Energy, 2017: 23-25). Such TMP’s also often include instructions for the mitigation of social impacts from truck movements such as: mud and debris; dust; vibrations; and community considerations (Third Energy, 2017: 26-29). Additionally, when chemicals have reached a site, they may be stored within double-skinned tanks to prevent chemical spillages (UKOOG, 2015).

Although it is important for operators to have robust strategies in place to prevent social and environment harm from occurring, it is arguable that there are still serious risks from intensive truck movements (some of which contain chemicals or hazardous wastewaters). Participants largely agreed with this and often spoke of transportation in a negative manner. For example, PN12 described chemicals as being at their “most dangerous” when they are being transported:

PN12: *"you shouldn't jump to conclusions obviously, the poison is the dose but, these are dangerous chemicals being transported by truck close to people's houses. I mean once they are mixed in with the fracking fluid and stuck in the ground, that may actually be when they are at their safest, er, the most dangerous time is when they are being transported in their concentrated form and handled on the surface."*

Alongside chemical transportation, the intense truck movements imperative for UHF operations will also produce diesel fumes from lorries which is damaging from an air pollution and climate change perspective (Jackson et al. 2014: 347; Mash et al. 2014: 334). As PN12 reveals:

PN12: *"whilst certainly there are exotic stuffs that are known carcinogens and stuff that we don't know about, there is also plenty of things we do know about that are damaging, just simply the diesel fumes from the lorries, we know that traffic causes air pollution in cities and that causes health problems you are talking at least a similar quantity of air pollution in (difficult to hear) a fracking site and that's from the industry's own figures. So, there you have an obvious source of harm in terms of the, you know, air pollution from the diesel engines."*

Furthermore, harmful diesel fumes are not only a concern from rigorous truck movements but are also prevalent from the actual act of hydraulic fracturing. As Jackson et al. (2014: 347) indicate: 'high-power diesel engines are also used for pumping the water, proppant (e.g., sand), and chemicals underground during hydraulic fracturing.' Therefore, diesel engines are an imperative part of the UHF process that are used to generate the immense pressures that are critical to the fracturing of competent shale rock.

6.3.3.3. *Public Health*

There are several avenues for the chemicals used in UHF to negatively affect public health. PN02, an anti-fracking campaigner, separates public health concerns into mental health issues and physical health issues:

PN02: *"it will have quite an impact, both physical and mental (short pause) er, the stress caused by the fracking process, the noise, the pollution, the sound, the light, the, you know for people living nearby, um, as proved elsewhere, well there's a chap in the United States, in Australia, s-s-suicide, farmer trying to sort of expose this, he couldn't take it anymore so, from a mental point of view, it can have a detrimental effect, but physically now I think it's 400 peer-reviewed reports, health reports, through various medical establishments, er, in the United States, and universities, um, have have shown the effects on on people, um, carcinogenic, um, induced illnesses from fracking, um, and I think the connections have been made, because there has been a before and after you know, people's health was ok before, you know, how is it that there is a big cluster around, er, fracking wells. Er, the other is respiratory, um, people are struggling, the other is skin (short pause) um, dermatological problems, again, these problems have been mounting to such an extent that um, neighbouring States like New York have banned fracking, you know, they see what has happened in Pennsylvania and they don't want it happening on their doorstep because they know that one of the greatest impacts has been on public health."*

Initially, PN02 talks about the negative mental health effects of UHF processes on people living close to fracking sites. These issues can take the form of stress which can occur as a result of various pollutions (sound and light) and has resulted in suicide in the most extreme cases. There are many potential impacts that fracking processes can have on mental health and Hirsch et al. (2017: 1) conducted a literature review on this specific topic finding that:

> "although persons living in fracking communities may experience some minimal, initial benefits such as land lease income or infrastructure development, they may also experience worry, anxiety, and depression about lifestyle, health, safety, and financial security, as well as exposure to neurotoxins and changes to the physical landscape. Indeed, entire communities can experience collective trauma as a result of the "boom/bust" cycle that often occurs when industries impinge on community life."

Secondly, PN02 discusses the physical health implications of fracking and how the process can induce illnesses. There are many academic, peer-reviewed journal articles and other organisational reports which directly link UHF to public health complications (some of the most influential articles include: Adgate et al. 2014; Colborn et al. 2011; Finkel and Hays, 2013; Jackson et al. 2014; Kibble et al. 2014; McDermott-Levy et al. 2013). Whilst many of these studies were produced in the United States or Australia, there are several reports and academic articles that already link UHF and public health concerns in the UK (Law et al. 2014; McCoy and Saunders, 2015). Although it is not possible to go through all of the potential public health implications of UHF in the UK (and such implications will vary from place to place depending on several local, geological and geographic factors), a snapshot of the most salient concerns from the literature include the human health implications associated with:

- Noise, light, dust and air pollutions emanating from UHF sites (Grear et al. 2014).
- Exposure to chemicals from truck spillages off-site (Burton Jr. et al. 2014; Wiseman, 2011: 9).
- Exposure to chemicals from spillages on-site (Burton Jr et al. 2014: 1680).

- Exposure to chemicals and other substances that have contaminated water aquifers, groundwaters or surface waters through hydraulic fracturing or spillages (Jackson et al. 2014).
- Exposure to wastewaters that are not disposed of correctly or treated sufficiently (Jackson et al. 2014).
- Potential injury resulting from infrastructure damage or from property damage from seismic activity (Bulgarelli, 2017; Logan, 2016: 211-212).
- GHG emissions from leaked methane, diesel emissions and $C0^2$ released from flaring. Such activities contribute to anthropocentric climate change which negatively effects the global human population (see: Broderick et al. 2011: 110 for more details with regards to shale gas and climate change).

Alongside public health concerns, participants also mentioned the term *commercial confidentiality* on several occasions.

6.3.3.4. *Commercial Confidentiality*

Strictly related to the use of chemicals within fracking fluids, operators must disclose the substances they use to the Environmental Regulator, but do not have to disclose such information to the public on the grounds of commercial confidentiality. Whilst the UKOOG (2013c: 29) have published guidelines recommending that operators should disclose chemical additives (including their characteristics, volume, concentration, and potential environmental and health risks) these are only guidelines and are therefore not enforceable standards. This is critically analysed by Hawkins (2015: 18) who explains that:

> 'Although the United Kingdom Onshore Operators Group (UKOOG) has issued best practice guidance for shale gas operators, it remains voluntary. Relevant legislation and regulatory requirements are collated in the guidance, as are references to other relevant oil and gas guidelines (e.g. the Well Integrity Guidelines) and industry

> best practices from the conventional sector. Monitoring and transparency within the industry are encouraged (including the public disclosure of fracturing fluids), but without enforceability mechanisms and supporting legislation many guidance provisions still fail to guarantee adequate environmental and health protection.'

Despite this, PN06 believes that the permitting process in the UK will lead to companies listing chemicals used publicly, creating a greater degree of transparency:

PN06: *"the question of their regulation in the US is a much bigger one than I suppose it is in the UK because obviously there is a permitting process where the companies have to list the chemicals, I think they have to list it publicly as well, um, on a website. So, I think that is certainly a good thing because it creates a greater degree for industry transparency, there isn't that feeling like they have something to hide which certainly happened, er, in the US because a lot of the fracking chemicals were hidden behind, um, (short pause) proprietary information protected by that sort of, um, as an industry secret."*

Although the listing of chemicals is currently voluntary (as discussed by Hawkins, 2015), the only UHF that has occurred in the UK to date at Preese Hall in 2011 did lead to the operator, Cuadrilla Resources, publicly displaying their chemical usage online (Cuadrilla Resources, 2016; no date).

PN09 discusses commercial confidentiality in much detail with regards to the chemicals used within UHF production processes. He suggests that some of the blends of chemicals will be proprietary (i.e. the operator will hold exclusive rights to that blend). He goes on to suggest that there is a competitive nature between operators in that they "are trying to develop more effective blends":

PN09: *"there is an ongoing discussion about the precise nature of what the companies are going to use and the reason that is, is largely commercial confidentiality. Some of the blends of chemicals which will be used are proprietary so, you know the companies are trying to steal (difficult to hear) from their competitors they are trying to develop more effective blends and they don't want to go and have to tell everybody what those blends are because if they are successful their companies will then know a lot about it and will copy them. So, there's a little bit of a debate going on as to how much information, um, fracking operators would have to disclose to the public as opposed to disclosing to regulators. Now, it might be, and I don't know if this is the case, but it might be that, er, (long pause) they will have to disclose information to the Environment Agency which they won't have to disclose to the public on grounds of commercial confidentiality. Um, and that's fairly standard of the regulatory process in general, there are quite a few things that don't get disclosed to the public on perfectly legitimate grounds of commercial confidentiality."*

In the United States, the federal government does not require companies to reveal chemicals used within UHF processes. At individual State level however, 28 States require the disclosure of some chemicals, with different states requiring varying levels of disclosure (Schipani, 2017). With regards to chemical composition and public disclosure, respective governments must decide between siding with companies (who would ultimately prefer commercial confidentiality) and keeping the public informed about chemical usage (Jasnoff, 2014: 1).

Despite this, PN20 suggests that such a lack of permission may not prevent an operator from finding a way to gain approval from the Environmental Regulator, implying that such companies are powerful and threatening in comparison to the EA:

PN20: *"the idea that somebody, that a little guy from the Environment Agency on perhaps £20,000 a year is going to turn up on their bicycle and tell Cuadrilla, er, that they are using chemicals that are dangerous, and when they ring back to the back office, er, their call is going to carry weight with Cuadrilla ringing, um, er, the department and saying, er, we have got some little oink who is getting in our way. Um, it is absolutely clear which one is going to win. These industries are very threatening."*

PN14, a water consultant, has a slightly different take on commercial confidentiality. She explains that companies may put chemical compositions on their websites in the first instance in order to prove themselves. However, over time, companies will begin to back-track on public disclosure in order to gain competitive advantage:

PN14: *"at the moment they only have to tell the agency. They have to disclose it to them. And I think that's (long pause), I don't know I trust the Environment Agency (laughs) but then I think because companies like Cuadrilla, you know, they are really desperate to prove themselves, I think they are willing to go that step further and put it on their websites. And like I say, when we get to full on production and there is competition that is when we could see that backsliding on public disclosure."*

These thoughts from PN14 may already contain some truth. Although the operations that took place at Preese Hall led to two minor earthquakes and a government-induced one-year moratorium on UHF in 2011, the company did disclose the chemicals that were used in the process. These included hydrochloric acid, glutaraldehyde biocide, surfactants and polyacrylamide (Cuadrilla Resources, no date).

PN18 sums up the issue with regards to commercial confidentiality by stating that companies “closely guard their own formulas” and try to obtain a “competitive advantage over one-another”:

PN18: *"people think maybe the companies are a bit shady about it because they closely guard their own formulas for using it and I suppose that’s one way they have tried to maintain, um, competitive advantage over one-another by having a system that works better in a particular formation than another company. But they have to disclose everything to the Environment Agency don’t they. But again, that’s probably a big difference between here and the States where they are probably very closely guarded…"*

It is clear to see here that competitive advantage is an important ethos of the UHF industry. If an operator develops a chemical solution that works well, the competitive protocol is to guard that knowledge rather than to share it as part of a united community.

6.3.3.5. *Conclusion*

It is very difficult to analyse the effects of chemical usage from UHF operations in the UK because fracking is currently only at an exploratory phase, rather than a production phase of development. This means that, although chemical additives will be used to enhance the process of UHF, they are not being used yet and any social or environmental harms that may result from such usage have not yet occurred.

Similarly, the chemicals to be used in UHF processes will certainly vary from site-to-site based on the operator, the underlying geology and on the trial and error nature of UHF production. PN04 explains this well from the point of view of the operator:

PN04: *"as you say it varies from well to well and I spoke to INEOS and asked well what are you going to be using and they said we don't know (short pause).*

I: *Until it gets to it yeah.*

PN04: *Exactly because they don't know what the formation is, um, and they don't know what will be available there either."*

The geology, then, clearly plays an important role in what chemicals are used in UHF processes and chemicals are used to enhance the process making it more economical and more efficient. This, however, conjures a further concern in terms of whether chemicals can be used towards the end of an UHF production process, in order to encourage increased flow rates as such rates begin to decline over time. An operator may be inclined to undertake such final stimulation if the well has not proved to be as economic as originally calculated, or if the operator thinks the well may still yield more hydrocarbons than what has already been produced. These issues where explored in the following quotation from PN08, a law academic:

PN08: *"at the moment there is very limited chemical content, it is approved by the agency. I think one of the questions people sometimes have is, once you have started fracturing the rock, if you have extracted quite a lot of oil or gas and it starts getting a little bit harder, might they change the chemicals that they are using in the process at that point to get more out. I think there is the potential for using other chemicals. I mean things like in the US where they pump benzene into the ground, you would just never get it past the Environment Agency here. Um, but yeah there is that question of kind of, chemicals in an industrial process and trying to ensure that they have been assessed adequately for the process they are in."*

Importantly, PN14 suggests that operators do not want to use hazardous substances in order to keep their social license to operate:

PN14: *"but I think, speaking with the companies they will be very keen to not use, sort of, anything hazardous and they will want to keep that license to operate."*

Although many would argue that operators do not have a social license to conduct UHF in the UK[31], PN14 provides a valuable point that operators are essentially functioning in order to produce hydrocarbons for economic purposes. Environmental and social harm is not the main goal for operators, even if their practices do result in such occurrences.

6.4. **Deductive Category Six: Well Integrity**

6.4.1. Introduction

To begin, it is important to briefly define what is meant by the term *well integrity* and other corresponding terms. It is also important to understand the importance of well integrity to the prevention of environmental and social harm.

According to the RSRAE (2012: 69) well integrity is 'the ability of the well to prevent hydrocarbons or operational fluids leaking into the surrounding environment'. Therefore, the integrity of the well is pivotal in terms of containing hydrocarbons and operational fluids and preventing such substances from coming into contact with the environment outside of the well. More specifically, King and King (2013) differentiate between the terms well barrier failure (WBF) and

[31] Wave 23 of the DBEIS (2017b: 5) public attitudes tracker found support for shale gas at just 13% with opposition to shale gas at 36%. Correspondingly, support for renewables was at 82% with opposition at 3% (DBEIS, 2017b: 4).

well integrity failure (WIF), terms that will be referred to in this research to describe the differences between the failure of a single well casing (WBF) and total well failure (WIF). The latter (WIF) is a situation where all barriers fail initiating a pathway for hydrocarbons and operation fluids to contaminate the environment. For a visual representation of multiple well barriers, see Appendix Three.

The results for this section (6.4.) will be split into participant responses that the researcher believed represented the view that fracking will have very little, or no effect, on well integrity (section 6.4.2.) and those that represent a negative view on well integrity (section 6.4.3.). Similar to section 5.3. on water resources, no participants were of the view that fracking would have a positive effect on well integrity.

6.4.2. <u>Fracking Will Have Very Little, or No Effect, on Well Integrity</u>

Participants mostly cited two pertinent reasons as to why fracking would have very little, or no effect on well integrity. These were the fact that wells have multiple casings (section 6.4.2.1.) therefore inferring that a failure of one of the casings does not lead to environmental or social harm as other casings may be successful in preventing substances escaping the well (WBF as opposed to WIF). Secondly, participants explained that if the design and construction of wells is undertaken correctly, then there should be no issues with regards to well integrity (section 6.4.2.2.).

6.4.2.1. *Multiple Casings*

PN01 infers that a number of strings of casing will be constructed in line with proper engineering practice. This includes cement (with cement bond logs, an acoustic test on the cement to check the cement job has been done properly). PN01 ends the following code by explaining that fracking is a heavily controlled process and that the greatest likelihood for gas leakage is in surface pipelines (which is true of natural gas now), rather than leakages resulting from well integrity issues or well failure:

“**PN01**: *There shouldn’t, they shouldn’t leak at all.*
I: *Ok. Not at all?*
PN01: *No I mean the um (short pause) there’ll be a number of strings of casing, you understand the strings of casing?*
I: *Yes.*
PN01: *Um there’ll be a number of strings of casing put in um in line with um (short pause) proper engineering practice.”*

PN05 also refers to multiple well casings in the following code. He suggests that, although some part of the well may have become comprised (failure of one or more, but not all of the casings of the well) this does not necessarily mean there has been a leak, even though that well failure has been reported:

PN05: *"there’s a difference between integrity issues which could be sort of an element of the well has become compromised but not necessarily the whole well because wells can be composed of different, um, casings, um (short pause) so sometimes the fact that an issue has been reported doesn’t mean that there has been a leak it just means that a part of the well has become compromised."*

Finally, PN14 denotes the conflicting studies and miscommunication around what is, and what is not, a well failure. She states that some studies cite numerous well failures even though that does not necessarily mean the well has failed to such an extent that that has caused a leak into the environment. This is because a well failure can constitute just one well casing and does not always mean every casing within a well has failed.

PN14: *"I think it is really important that we get this right. There are quite a lot of conflicting studies and I think there is a lot of conflicting, sort of, views and I think there is a lot of miscommunication between what's a well failure and what isn't. I think some of the studies cite a number of well failure's but that doesn't necessarily mean that they leaked into the environment because it's one failure within a multiple barrier system. So, one layer could have failed but the other two might have stayed intact. But because it's failed they have to report it and so there are studies that just compile those reports."*

6.4.2.2. *Construction of the Well*

Alongside the protective purposes of multiple well casings, PN17 and PN09 convey the significance of well design and construction in relation to preventing any well integrity issues. According to PN17, the proper design and construction of a well severely diminishes the chances of fire, explosion, and losses of well integrity:

PN17: *"If the operator gets the design and the construction of the well right, the chances of a loss of integrity, er, and therefore the chances of fire and explosion are very much diminished."*

PN09 draws a comparison between conventional hydraulic fracturing operations and unconventional hydraulic fracturing operations stating that the well head will be no different in both practices. As a result of this, he has no more concerns with one form of practice over the other. PN09 continues by saying the same is true of well integrity. The actual act of hydraulic fracturing, for PN09, is the action that starts the gas flowing from the shale rock which is a very short-lived operation driven by geological pressure:

PN09: *"the well head is going to be no different from any conventional activity so from that point of view I would have no more concerns from fracking than I would from any other kind of onshore* *oil and gas. Um, well integrity ditto, er, and the frack is, the frack is, er, it is the thing which starts the gas flowing. Um, the frack is actually a very short-lived thing and from that point onwards it's, um, a flow which, which is being driven by geological pressure. Um, so in terms of leaks, leaks from fracked wells, as I understand it I don't think there is any distinction between fracked and non-fracked wells, it's something that would be regulated irrespective of the activity."*

Although PN09 is correct in stating that a flow induced by hydraulic fracturing is driven by geological pressure, this gives a false impression that the flow will continue indefinitely. When hydraulic fracturing occurs (inducing cracks in a rock formation), the overlying geologic pressure squashes the cracks back together. This squeezing of induced fractures is the result of the depth of shale formations that exist at around 3 kilometres below the earth's surface in the UK. Whilst the squeezing of fissures enables hydrocarbons to flow out of the well initially, geologic pressure (with time) forces the fissures to close. When this happens fully, the gas is no longer able to escape out of the shale rock and into the well. As Stephenson (2015: 59) states, gas:

> 'will rush through the right-angled passageways in a mad dash to get into the well. This is because of the pressure difference between the well and the rock thousands of feet down. The weight of the rock above will squeeze the gas out of the well… you might also find that fractures deep down are squeezed so tightly together because of the pressure that they don't let the gas flow. Or they might be choked up with other minerals formed later. So, you might need to 'open the shale up' a little by widening the existing fractures, extending them and even making new ones.'

Therefore, whilst PN09 is correct in stating that flow is initially driven by geological pressure, he fails to assert that such a flow is short-lived and chemical additives (and re-fracturing) are required to stimulate shale rock and to keep fractures open for as long as possible (to produce the greatest quantity of gas feasible). PN09 is also of the opinion that this process is the same for both conventional and unconventional wells (meaning well integrity will be the same for both forms of technology). This is simply not the case. UHF is significantly different in the resource that is targeted (impermeable shale as opposed to more permeable, conventional formations such as limestone or sandstone) and technology that is used. This results in a very different process in terms of the number of induced fractures that are able to be undertaken, the chemicals that are needed to induce such fractures in a different, deeper rock formation, the amount of pressure that is required to fracture the well, and the type and quantity of gas that is able to be extracted. This leads to different well designs that follow industry guidelines, assessed on a case by case basis by the independent well examiner (HSE, no date).

Despite some participants holding the opinion that fracking will have very little, if any effect, on the integrity of wells, most participants were of the view that fracking will have a negative effect on well integrity which will now be analysed in further detail.

6.4.3. <u>Fracking Will Have a Negative Effect on Well Integrity</u>

This section will focus on the codes that express that fracking will in some way have a negative effect on well integrity. This is further sub-divided into three distinct sections. Firstly, section 6.4.3.1. will consider the percentage of well failures (both in terms of participant predictions and academic research). Secondly, section 6.4.3.2. will analyse participant's responses that stated all wells will fail over time. and section 6.4.3.4. will consider the long-term monitoring of wells and other long-term issues surrounding well integrity.

6.4.3.1. *Percentage of Well Failures*

Participants gave varied estimations as to the percentages of unconventional hydraulically fractured wells that would either fail or lose their integrity in some way. These estimations were often given in percentages (as opposed to total number of wells in a given place over a specific timeframe). Percentages cited were between 5%-10% of all wells. PN02, an anti-fracking campaigner, for example, suggested that “up to 5% of wells” lose their integrity in the first year:

PN02: *"it’s been monitored, er, and recorded that up to 5% of wells, er, er, their integrity is lost in the first year. Now, again they say oh, this won’t happen here they will improve the type of cement that they use."*

Similarly, PN03, an anti-fracking campaigner, cited that 10% fail within the first year. Significantly, PN03, also claims that all wells will fail eventually over time (this will be discussed in more detail in section 6.4.3.2.):

PN03: *"Plus, it’s not clean-upable, they know that as well. Once the damage is done every well-head will leak given time, and a lot leak within just a short time. Um, if you listen to Professor Ingraffea on on well casing’s you’ll see that the majority fail within a very very short time. All casings fail all fail eventually…*
I: *Over time, yeah…*
PN03: *So, over, time, a large number of them I can’t remember the percentage of the top of my head I will have to look it up, 10% fail within the first year*
I: *Yeah, I’ve heard a similar…*
PN03: *34% fail within the first five years you know whatever, that’s a fact.”*

PN03 finishes by stating that 34% of wells fail within the first five years, stating this as a fact without giving any evidence to back this statement up, besides the work of Professor Ingraffea. However, according to Ingraffea et al. (2014: 10958) less than 10% of unconventional wells in Pennsylvania between 2000-2012 (according to data from Pennsylvania State inspection records), showed comprised cement or casing integrity issues:

> "Pennsylvania state inspection records show compromised cement and/or casing integrity in 0.7–9.1% of the active oil and gas wells drilled since 2000, with a 1.6- to 2.7-fold higher risk in unconventional wells spudded since 2009 relative to conventional well types. Hazard modelling suggests that the cumulative loss of structural integrity in wells across the state may actually be slightly higher than this, and upward of 12% for unconventional wells drilled since January 2009."

Whilst it is clear that some wells (both conventional and unconventional) clearly do experience well integrity issues for various different reasons, Ingraffea et al.'s (2014: 10956) study only considers wells in one geographical location (the US State of Pennsylvania) and also notes that a well integrity issue does not necessarily lead to environmental or social harm:

> "Although not every instance of loss of zonal isolation will lead to such events, the incidence rate of cement/casing impairments and failures can provide some insight into the scale of current and future problems."

Ingraffea et al. (2014: 10956) use the term 'zonal isolation' in the same way that King and King (2013) differentiate between WBF and WIF (that zonal isolation, or a singular well barrier failure does not necessarily lead to absolute well integrity failure).

Data collected from various different scientists on the extent of well integrity and well failure in the United States generally reports that fewer than 10% of unconventional oil and gas wells experience well integrity issues. This can be seen in the following Table (Table Nine) that presents statistics from a literature review conducted by Jackson (2014: 10902) on rates of well failure:

Author/s	Time Period	% of Reported Well Failures	Number of Wells	Location
Considine et al. (2013)	2008-2011	2.6% (well barrier or integrity failure)	3,533 gas wells	Marcellus Shale Gas Drilling (US)
Davies et al. (2014)	2005-2013	6.3% (well barrier failure or well integrity failure)	8,030 (conventional and unconventional wells)	Marcellus Shale Gas Drilling (United States)
Ingraffea et al. (2014)	2000-2012	6.2% for unconventional wells and 1.0% for conventional wells	41,381 (conventional and unconventional wells)	Pennsylvania
Vidic et al. (2013)	2008-2013	3.4% (well barrier leakage)	6,466	No text access

Table Nine: *Rates of Well Failure*. Source: Jackson (2014: 10902).

This Table identifies two important things with regards to well integrity. Firstly, well integrity issues are more prevalent in unconventional wells (undoubtedly due to the technological, pressure and geological target differences between conventional and unconventional wells). Secondly, it is very difficult to find data specifically on unconventional wells, and furthermore, data on unconventional wells that specifically identify total well integrity failure (as opposed to well barrier failure). Total well integrity failure is of greater importance to this research because of the social and environmental harm that could occur. It is likely, from the above studies, that total well integrity is more common in unconventional wells but may be much lower than the total reports of singular WBF.

There are many reasons why both WBF and WIF may occur within oil and gas wells and a detailed synopsis is provided in the following quotation from Ingraffea et al. (2014: 10955):

> "Leaking oil and gas wells have long been recognized as a potential mechanism of subsurface migration of thermogenic and biogenic methane, as well as heavier n-alkanes, to the surface. A leaking well, in this context, is one in which zonal isolation along the wellbore is compromised due to a structural integrity failure of one or more of the cement and/or casing barriers. Such loss of integrity can lead to direct emissions to the atmosphere through one or more leaking annuli and/or subsurface migration of fluids (gas and/or liquid) to groundwater, surface waters, or the atmosphere. Cement barriers may fail at any time over the life of a well for a number of reasons, including hydrostatic imbalances caused by inappropriate cement density, inadequately cleaned bore holes, premature gelation of the cement, excessive fluid loss in the cement, high permeability in the cement slurry, cement shrinkage, radial cracking due to pressure fluctuations in the casings, poor interfacial bonding, and normal deterioration with age. Casing may fail due to failed casing joints, casing collapse, and corrosion. Loss of zonal isolation creates pressure differentials between the formations intersected by the wellbore and the open barrier(s)."

Although the first two codes in this section were taken from the transcripts of two anti-fracking campaigners, PN05, an academic geologist, also quoted that 3%-5% of wells have some form of integrity issue reported:

PN05: *"it's clear from the datasets that are made available in Pennsylvania that a small percentage of the wells have integrity issues, usually there are different datasets that produce slightly different numbers but typically sort of 3 to 5% of wells have had some type of integrity issue reported."*

PN05 (below) provides a quotation that sums up this section effectively. He explains that some wells will fail (whether that be in the sense of a WBF or total WIF). However, the important question is the impact that that failure has (on people, and the environment), and whose responsibility it is to monitor well failure. PN05 suggests that, during well production, the operator should be responsible for managing well integrity. However, although leaks occur, PN05 implies that operators do not want wells to leak because they want to extract as much oil or gas as possible:

PN05: *"I think we can say with a reasonable degree of certainty that some wells will fail in some sense, um, and then the question is what impact does that have and who is monitoring it? Um, now I'd say during the lifetime of a well production particularly the companies should be keeping an eye on that and I guess in some sense they don't want it to be leaking at all because they want to produce as much oil or gas from it. So, the idea that they want them to leak is probably a little bit, um, (short pause) erroneous..."*

Whilst this quotation raises important questions with regards to well integrity at the production phase of UHF, PN05 does not indicate who should be monitoring wells after wells have been decommissioned. This is important because several participants alluded to the thought that, over time, all wells fail thereby allowing operational fluids and other substances to escape the well causing environmental and social harm.

6.4.3.2. *All Wells Fail Over Time*

The main concern regarding the potential for all wells to leak over time is the fact that (given enough time) concrete will eventually break down and steel will corrode. This is explained by PN04:

PN04: *"there's also some work by, um, the ReFine project on below ground contamination and there's a guy called Richard Davies whose professor of heading the ReFine project and he's posted somewhere I can't remember where but you could track it down, that you know (short pause) all wells leak eventually. That the concrete and the steel will protect the aquifer, that assumes that it's going to do that forever and there may well be the contents of that well could at some point, um (sighs), be distributed into rock formations because the concrete cracks and the steel corrodes."*

Therefore, even if a well has not experienced any well integrity issues during its production lifetime it could experience problems in the indefinite future. Additionally, even if such a well has been successfully decommissioned, well integrity issues could occur from the breakdown of steel and concrete over time, and this is a particular problem where there is no long-term maintenance of decommissioned wells. A well that has no person, company or agency responsible for it legally or financially is termed an *orphan well* (Orphan Well Association, 2003). This is already a problem onshore in the UK where many conventional, abandoned, oil and gas wells have no clear ownership. According to Davies et al. (2014: 239):

> "In the UK, 2152 hydrocarbon wells were drilled onshore between 1902 and 2013 mainly targeting conventional reservoirs. UK regulations, like those of other jurisdictions, include reclamation of the well site after well abandonment. As such, there is no visible evidence of 65.2% of these well sites on the land surface today and monitoring is not carried out. The ownership of up to 53% of wells in the UK is unclear; we estimate that between 50 and 100 are orphaned. Of 143 active UK wells that were producing at the end of 2000, one has evidence of a well integrity failure."

Although Davies et. al (2014: 239) denote that only one well (that was active at the end of the year 2000) 'has evidence of a well integrity failure' this does not mean that more wells will experience integrity issues in the future. Furthermore, this analysis is based on mainly conventional wells in the UK and not unconventional wells that have used horizontal drilling and hydraulic fracturing. Ingraffea et al. (2014) found that unconventional wells are 'six times more likely to show problems than conventional wells' (Jackson, 2014: 10902; In: Ingraffea et al. 2014) meaning that and increase in UHF wells in the UK could see an increase in well integrity problems in the future. The only case of high-pressure, hydraulic fracturing in the UK at the time the research was conducted (the Preese Hall-1 well near Blackpool drilled by Cuadrilla Resources in 2011) did result in well casing deformation but overall well integrity was not compromised (Green et al. 2012: 2).

PN04 (below) again goes on to discuss research conducted by the ReFINE project, the authors of which attempted to test the integrity of onshore decommissioned oil and gas wells in the UK by measuring above ground methane levels at the wells compared to nearby control areas (Boothroyd et al. 2016). Whilst this study did find that 30% of wells had methane 'at the soil surface that was significantly larger than their respective control' (Boothroyd et al. 2016: 461) the authors were unable to determine the exact source of the emission (although they interpreted it to be the result of well failure).

PN04: *"the work of the ReFINE project. There was a paper that they produced, er, I think it was probably last year now, um, on methane leaks from established conventional wells and I think they found that around a third of them leaked, um, but the level of methane was quite low and I think they did it by comparing methane in soil around wells and comparing it with levels um in a control. So, a fair number of wells do leak but the level of methane leaks is quite small according to this. But these were conventional wells, some of them quite old, so you might argue, well, they probably weren't made very well and you would expect to have a better quality of casing and* *completion and all that sort of thing now. Well (short pause) I suppose I'll come back to his other element that concrete cracks and steel erodes eventually, it comes back to who is going to be checking (short pause) and once these wells have been abandoned who carries on looking to see whether they are still OK?"*

Although the extent of long-term well integrity issues relating to onshore oil and gas wells in the UK is unknown, 'overtime it is expected that the condition of abandoned wells will deteriorate' (Miyazaki, 2009, in: Boothroyd et al. 2016: 462), and this is arguably more likely to happen in unconventional wells (Ingraffea et al. 2014).

PN07, a Parish Councillor, also agrees that all wells will leak eventually, additionally stating that 4% of wells will leak straight away:

PN07: *"he came out with some figures and these are actually industry figures which I think, 4% of wells leak straight away and then, you know, this increases exponentially over time and then eventually, as I said before, all wells will leak, regardless of what they say they can do."*

PN19, an anti-fracking campaigner, also expresses the view that concrete specifically will always break over time. However, PN19 is incorrect in stating that there is no metal involved in the casing of wells. On the contrary, steel is used in multiple casing strings to protect operational fluids from escaping the well (see Appendix Three).

PN19: *"The well integrity, the casing that they use to drill down is literally just concrete. Anybody who is in the construction trade and uses concrete knows that, whilst it is quite resilient, it will and can break. They expect the wells to break, um, they know that they will break, each and every one of them will break at some point, every* *well that they drill will break. The casings that they put down are not 100% secure and they never will be, er, and they can't guarantee that."*

6.4.3.3. *Long-Term Well Monitoring*

The final issue raised by participants with regards to the potential impact of UHF on well integrity was the responsibility for long-term well monitoring in the UK. Essentially, responsibility for integrity lies with the operator whose operations are scrutinised by the Independent Well Examiner (the HSE), and must follow certain regulations[32] and industry guidelines[33] (HSE, no date:b). However, these regulations only apply up until well abandonment and 'one should bear in mind that monitoring of abandoned wells does not take place in the UK' (Davies et al. 2014: 252). Therefore, well integrity is a huge issue in the long-term if we refer back to section 6.4.3.2. and consider the possibility that all wells may fail given a significant enough timeframe. This notion is summed up well by PN05:

PN05: *"the question then really comes down to well, um, over the longer timeframe, um, some of the wells will fail and if the company has left the scene then, if it has effectively closed down the business and moved away, who is responsible for the monitoring and who is responsible for any potential impacts? And at the moment in the UK that is, at least not in my mind, clear, what would happen."*

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[32] According to the HSE (no date:b), these include the Offshore Installations and Wells (Design and Construction) Regulations, the Borehole Sites and Operations Regulations, and other recognised industry standards regarding well design and construction such as the UKOOG Shale Gas Guidelines and UK Well Life Cycle Integrity Guidelines.

[33] Hawkins (2015: 18) explains that guidelines such as the best practice guidelines for shale gas operators produced by UKOOG remain voluntary rather than mandatory.

Similarly, PN07 relates the issue of long-term well monitoring to the properties of well casings (steel and cement) which may break down over different time spans:

PN07: *“one of the biggest concerns that we have is that over time all wells fail. Concrete crumbles and breaks down. Steel rusts and corrodes. And you know, overtime that integrity may break down. It may be 50 years it may be 100 years but whose going to monitor it in that time?"*

Finally, PN08 suggests that over a longer time frame when a company may no longer be operational (or even “exist”), the responsibility may fall on the landowner to restore any contaminated land which may result from a loss of well integrity in the long-term:

PN08: *"I think the casing and the well integrity is one of the big issues in relation to contamination. Um, one of the concerns at the moment is that it is relatively well hidden within the planning guidance, um, but it does say that an operator is responsible for a site through to abandonment, Um, however, if the operator can’t be found, actually the landowner is potentially responsible. Which I think at the moment, given that some of the exploration companies don’t actually have a lot of capital, a lot are subsidiaries which don’t actually have much money that is a potential concern which is if you have a well on land, it starts leaking and the operator can’t be found, the company no longer exists… it’s bust, um, you are potentially going to find yourself liable, um, for kind of restoring or remedying that."*

This situation is confirmed by the DCLG (2014) who confirm that ‘responsibility for the restoration and aftercare of mineral sites, including financial responsibility, lies with the minerals operator and, in the case of default, with the landowner.’ Default responsibility resting with the landowner, then, has clear implications for environmental justice (Lampkin, In Press) in terms of whether a landowner is able to afford the (potentially expensive) restoration of contaminated land from UHF operations, and, in either situation, what the consequences will be for ecological harm resulting from contaminated land.

6.4.4. <u>Conclusion</u>

Ultimately, the design of each well will vary from place to place depending on the operator and, therefore, the impact of a loss of well integrity is dependent on a number of factors. This is summed up well by PN05:

PN05: *"the amount of impact would depend ultimately on who built the wells, how, and how many of them there were and so it's something that does need careful consideration..."*

Participants responses have been divided into two sections: the thought that fracking will have very little, or no effect, on well integrity (section 6.4.2.) and responses surrounding the belief that fracking will have a negative effect on well integrity (section 6.4.3.). With regards to section 6.4.2., participants often brought up the multiple well casings that will be used to contain substances within the well. Furthermore, participants were aware that a single WBF does not necessarily result in a full WIF where all integrity is lost creating a pathway for contaminants to enter the natural environment. Alongside this, participants were concerned about the design and construction of wells, inferring that proper construction would prevent any subsequent well integrity issues.

However, participants largely discussed three main points with regards to the potential negative impact of fracking on well integrity in the UK. In particular, participants were concerned with rates of well failure and the possibility that all wells may fail over time due to the nature of well casing material (concrete erodes and steel rusts over time). Concerns were therefore raised about the long-term well integrity of shale gas wells in the UK. Similarly, participants were also apprehensive about the long-term monitoring of wells and highlighted the lack of any cohesive plan to monitor shale gas wells in the UK. The implications of well integrity, therefore, in the long-term, could be significant if there is no accountability for environmental harm that may occur post-well abandonment, with the possibility of liability falling on the landowner (DCLG, 2014).

6.5. **Deductive Category Seven: Flaring**

6.5.1. Introduction

Before beginning this section, it is important to understand what is meant by the term *flaring* and why it is often employed during oil and gas extraction processes. According to Schlumberger (no date), ‘flaring is a means of disposal used when there is no way to transport the gas to market and the operator cannot use the gas for another purpose.’ Essentially, when drilling a well (pre-production phase, see Appendix One), the gas that first comes to the surface of the well is known as *dirty gas* that is a mixture of gas and other products that are used in the initiation of the well. PN16, an oil and gas professional, explained the situation very competently:

PN16: *"what people don’t know is exactly how gas, er, is exploited in the first place, how it is drawn from the ground. Er, so, once you create your well and, er, it’s not entirely clean yet you need to, the first gas that will come up will come up with a lot of the products which you use to create the well and the fracture in the first place. That is dirty gas. It is very difficult to convince the National Grid to accept your dirty gas. Yeah? You need to create, you need to have free-flowing and clean gas before, of a certain quality, (difficult to hear) and composition before the National Grid (difficult to hear)* *distributor, will accept it. Therefore, there is a requirement for you to dispose of a certain amount of gas as, um, when you clean up the well, we tend to call it cleaning up the well. So, in which case you will use some form of flaring."*

Therefore, if dirty gas is not suitable for the national grid immediately, it has to be disposed of and this most commonly occurs through the method of flaring, a technique used to burn gas into the atmosphere. Burning off gas in this manner turns the gas into (largely) carbon dioxide which is much less harmful to the environment than the direct release of methane. The constituents of natural gas vary from place to place depending upon geological conditions, but Speight (2013: 2) estimates that methane makes up around 85% of natural gas. This is significant because methane is a GHG that is '25 times more potent than carbon dioxide over a 100-year time horizon' (Karion et al. 2013: 4393). Therefore, flaring dirty gas that predominately consists of methane, can be seen as a greener waste disposal solution than simply releasing (venting) gas into the atmosphere in its original form. Whilst the release of $C0^{2}$ is still undesirable in environmental terms ($C0^{2}$ is also a GHG), it is cleaner than releasing pure methane.

This section deals specifically with participants responses to the question asked of them concerning flaring (see Appendix Seven). The researcher has divided these responses into three succinct sections. Section 6.5.2. considers participants responses that the researcher believes constitute the idea that flaring will have very little or no effect on the environment. Section 6.5.3. considers participants responses that the researcher believes constitute the idea flaring will have a negative effect on the environment. Finally, section 6.5.4. considers other participant responses around the subject of flaring, but do not suggest that such ideas are positive or negative.

6.5.2. <u>Flaring Will Have Very Little or No Effect on the Environment</u>

Firstly, PN05 explains that shale gas sites in particular (in comparison to oil production sites), should only necessitate a small quantity of flaring. This differs from oil production because an operator may flare off gas at the production stage as operations and facilities are designed around the production of oil as opposed to gas:

PN05: "*particularly a shale gas site you would anticipate that flaring would not really be required very often because you would be trying to keep all the gas. If it's a shale oil site then it would be a bit different you may not want the gas and so the gas might be considered for flaring...*"

PN09 (below) suggests that whilst flaring is unlikely to be used, flares will be in place as a safety measure in case "anything went significantly wrong and you had a sudden escape of gas". Furthermore, PN09 suggests that operators do not want to waste any gas. The whole purpose of production is to collect gas to sell rather than to waste and flare off gas unnecessarily:

PN09: *"Once we get to the operational phase, there is no question, there's no question of flaring being allowed. There might be flares in place and in fact it is likely that there might be flares in place because if anything went significantly wrong and you had a sudden escape of gas it would be much better to flare that in a controlled way rather than just allow it to drift away and potentially combust. Um, but on a day-to-day operational basis when it comes down to it the operator doesn't want to waste any gas they want to use it they want to sell it. So an operational well once it is fracked and the gas is flowing that gas will simply will collected transmitted and used, um, so flares won't be used."*

PN13, a consultant geologist, reinforces the regulation around flaring gas and that, subsequently, flaring will be conducted in a controlled manner:

PN13: *"flaring will be under a controlled, within a controlled and regulated environment. So, it will be used I would suspect but it will be in a controlled manner."*

Indeed, there is specific reference to the monitoring of emissions of methane to the air in the *Infrastructure Act 2015* (s.50) that requires 'an environmental permit which contains a condition requiring compliance with a waste management plan which provides for the monitoring of emissions of methane into the air for the period of the permit'. The EA (2016) are responsible for monitoring airborne emissions of methane. Waste gases must be flared and be done so with an enclosed flare to prevent excess noise and light pollution that is associated with open flare systems (EA, no date: 2).

Whilst legislation and regulation serve the purpose of limiting and controlling emissions, this does not mean that flaring is a perfect process as flare gas still contributes negatively to GHG emissions (and subsequently, climate change). In fact, flaring is a significant global environmental problem where:

> 'thousands of gas flares at oil production sites around the globe burn approximately 140 billion cubic meters of natural gas annually, causing more than 300 million tons of $C0^2$ to be emitted to the atmosphere. Flaring of gas contributes to climate change and impacts the environment through emission of $C0^2$, black carbon and other pollutants. It also wastes a valuable energy resource that could be used to advance the sustainable development of producing countries' (World Bank, 2017).

Whilst flaring emissions from UHF in the UK would only contribute a tiny fraction of global flaring emissions, it is still a contributor. This is a serious environmental concern for the World Bank who have the objective of eliminating routine flaring activities by 2030 (World Bank, 2017).

The final quotation in this section again suggests that operators do not want to flare gas, the purpose of UHF is to collect gas. Flaring is a necessary activity in the initiation of UHF wells particularly at early stages in the process. According to PN17, an operator may flare gas in the initial stages when testing the flow rate. Only if an economically viable flow rate is detected will an operator continue with the production process:

PN17: *"the industry doesn't want to, they are interested in revenue, um, and so they don't want to flare excess amounts of gas or oil, um. What they'll want to do is, they'll want to test, um, how much gas they can produce from the well and that will probably necessitate flaring, um, for some period. Er, but they'll want to move as quickly as possible into a production phase so, I wouldn't anticipate, um, you know, a huge amount of flaring in this country because they'll want to, once they, once they've got some sort of assurance about the flow rate they'll be moving into, if it is economically viable, they'll be moving into collecting the gas as usual."*

This section has highlighted views from participants that flaring will only occur for a short period of time and that operators ultimately aim to collect gas and only flare at an early stage in the process where this is necessary. Furthermore, actions are taken to mitigate the social impact of flaring by restricting noise and visual impacts via the use of enclose flares as opposed to traditional open flares. These *green completions* are a necessary component to UHF but still contribute social and environmental harm. The following section will explore these issues further by considering participant responses that reflect ideas around the potential negative impacts of flaring.

6.5.3. Flaring Will Have a Negative Effect on the Environment

Participants brought up several different issues with regards to flaring that are relevant to this section. Firstly, PN02, an anti-fracking campaigner, identified the greater climatic impact of methane release compared to $C0^2$ release:

PN02: *"Well my understanding is that it will be built into the process, that it will be allowed, um, and, er, the effects in this area, East Lancashire won't just be, er, toxic substances but the main one Methane which is 27 times more potent as a Greenhouse Gas than* $C0^2$*, um will just exacerbate, um, and increase climate change."*

Whilst such an argument is clearly more applicable to venting than flaring, the potency of methane emissions is still important as methane may escape at various different stages of the UHF process. According to Jackson et al. (2014: 347):

> "Potential emissions during production and processing (e.g., dehydration and separation) include fugitive emissions of natural gas or oil vapors from equipment leaks, intentional venting from oil and produced-water storage tanks and wastewater ponds, and incomplete combustion during flaring."

Alongside PN02 (above) many other participants also alluded to the different substances that may be contained within natural gas that are potentially problematic (in environmental terms) when flared. The following responses from PN03 and PN04 are just two examples:

PN03: *"flaring and venting is massively packed with volatile organic compounds, er, with benzene, er, with all sorts of things."*

PN04: *"people are very concerned about flaring because the by-products of flaring are (short pause) air pollutants and all sorts of products that come out of them that are potentially dangerous. Not* *necessarily at the levels that there would be from one flare but um, (omitted – confidentiality) in East Yorkshire and their flare wasn't efficiently combusting the gas, it was partially igniting and they were, they got a warning notice from the Environment Agency for breaching their Environmental Permit. And there was Benzene and Volatile Organic Compounds coming out of that flare that people got quite concerned about."*

Additionally, PN05 suggested that companies would not want to conduct a significant amount of flaring because of visual implications:

PN05: *"I think it would be, um, (short pause) difficult in some respects in terms of both the social and environmental perception for companies to do much of it, um, at least onshore because it is very visible, people notice very quickly."*

However, what PN05 does not mention is the enclosed nature of flares for the purposes of UHF which will prevent (to some extent) the visual implications of such a method. PN16 correctly states that you can conduct flaring more discretely using a flare box which lowers the visual impact:

PN16: *"if you use a straight forward flare tip you will be seeing a bright orange flame in the field. Um, there are ways of doing it discretely in a flare box, so, you can bring a big container basically, a big upstanding container to site and have a combustion process within some confines which, um, make visual impact a lot lower. Whatever you do, there is a certain amount of clean-up that you require to do a measurement as you do the clean-up in order to achieve your end goal which is to sell the clean gas off to the National Grid."*

When discussing flaring, participants often incorporated venting into their arguments often suggesting that venting is more socially and environmentally harmful than flaring:

PN07: *"flaring is better than venting because at least you haven't got pure Methane being vented into the atmosphere which is far more potent Greenhouse gas wise, than, um, than the flaring because obviously, that's been burnt you've got you've got Carbon Dioxide, but you've also got, um, you know, your black carbon and all your other things that you get from burning the methane. I'm not sure they are going to be allowed to do it on a significant basis in the UK."*

PN12: *"there will be flaring unless they invest very heavily into technology to store to, basically, if gas comes to the surface that they can't tap off and store it either gets released into the atmosphere or flared. Er, of the two options, flaring is probably the least worst but it is not a good option. Um, I mean apart from you are burning a fossil fuel, again in someone's back yard, er, apart from the effect on wildlife and generally speaking on the neighbours, it's not something people want in a rural area."*

Whilst the EA (no date: 2) suggest that venting will not be permitted as a method for disposing of waste gases contained within wastewaters, it is unclear whether venting would be permitted for dirty gas returning from a well as an airborne emission. However, the instillation of flares suggests that such dirty gas will be flared rather than vented.

6.5.4. Other Codes

Alongside participants responses that suggested flaring would have no effect (or very little effect), or a negative effect on the environment, participants did state other issues around flaring that do not fit neatly into either of these categories. For example, PN05 suggests that flaring is the simplest solution to disposing of waste gases where dirty gas is not suitable for production or collection in any way:

PN05: *"particularly during the exploration phase where you are not actually set up to produce the gas if you do get gas being produced then flaring it is generally the simplest way of dealing with it, um, when you are not actually in a position to produce it and collect it for usage."*

Similarly, PN09 suggests that flaring may be the only way of practically dealing with waste gases in the short-term:

PN09: *"It is possible that some form of flaring would have to take place during the exploratory phase because at that point you don't know what the composition or the volume of the gas is coming out of the ground are likely to be and it may fluctuate and it may well be the only practical way of dealing, in the short term, with very small amounts of gas, um, is to flare them."*

PN14 also suggests that flaring is a necessary component of UHF operations. Although "green completions" are desirable, PN14 suggests that they are not always plausible:

PN14: *"what people are after is for fracking companies to use green completions, um, which is a sort of, casual term so that they don't flare the waste gases. Um, but I've heard the companies say that that's not possible at exploration and the EA have supported that, um, so they will be allowed to flare."*

Similarly, PN20 suggests that flaring is a necessary constituent of UHF operations because the excess gases that come to the surface of a well at the early stages of development need to be burnt to avoid explosions. He also suggests that there is no alternative to flaring in terms of disposing of excess gases, although a lack of an alternative does not necessarily make it the right thing to do:

PN20: *"it has to be used in the UK unless you want explosions. You cannot do fracking, um, without burning off the excess gases, er, that come out, particularly in the early stages before it gets to a predictable flow. So, technologically, there is no alternative. Um, now, that doesn't make it right."*

PN18 also suggests that enclosed flares will be utilised as opposed to open flares suggesting that this is the preferred method for waste gas disposal (over open flares or venting processes):

PN18: *"it is more than likely that they will flare, um, for flow-testing purposes. Um… burning as much of it as they can with an enclosed flare, rather than it just being an unguarded one."*

6.5.5. <u>Conclusion</u>

Section 6.5. has dealt specifically with participants responses to the topic of flaring in terms of social and environmental harm. Section 6.5.1. (introduction) addressed the issue of why flaring is necessary. The reasoning for this is that, when initially drilling a well, gas comes to the surface that is a mixture of sub-surface gas, chemicals used in the drilling of the well, and sub-surface compounds that vary depending on the geologic conditions of the particular area. PN16, an oil and gas professional, asserted that such gas is known as "dirty gas" that is not suitable to go straight into the National Grid. As a result, such gas is flared as a waste disposal method. Flaring is preferred over venting because converting methane to $C0^2$ is less damaging in an environmental sense. This is because methane is a much more potent GHG than $C0^2$. It has also been discovered that flaring facilities are advantageous for safety reasons and can be used to burn gas in the event that this is needed (EA, 2017).

Section 6.5.2. addressed participant responses that suggest fracking will have very little, or no effect on the environment. Participants suggested that flaring will only occur for a short period of time, and that, ultimately, operators do not want to flare gas. The ambition of UHF is to extract and sell gas, therefore, operators will only flare poor quality gas, and produce as much clean gas as possible.

Furthermore, PN13 alluded to the fact that flaring will be regulated and controlled. The *Infrastructure Act 2015* requires a permit system for emissions which is required for flaring (regulated by the EA). However, whilst venting is not permitted as a waste gas disposal method, it is unclear whether venting will be permitted for gas originating from a well. The instillation of a flare at a fracking site suggests that flaring will be utilised over venting.

Section 6.5.3. considered participants responses that suggest flaring will have a negative effect on the environment. There was a concern that certain substances used in, or resulting from, UHF processes may be harmful to both the environment and public health. Such substances included methane, VOC's, benzene and other "air-pollutants" (PN04). Finally, many participants implied that flaring was a form of airborne emission of $C0^2$ into the atmosphere, which is a negative externality of the UHF process for the environment, nearby communities, and climate change. However, it was also discussed that attempts will be made by operators (under the instruction of the EA) to mitigate the visual implications of open flare systems on local communities by the use of enclosed flares. Whilst this limits visual intrusion, it does not prevent local airborne pollution associated with flaring or contributions to GHG emissions.

Finally, participants suggested that flaring is the easiest and simplest method of waste disposal for dirty gas. Whilst "green completions" are desirable (PN14), flaring is a necessary component to the UHF processes that is used early in the process before a clean flow of gas has been established by the operator.

6.6. Conclusion to Results Chapter (Other)

Chapter Six has considered participant responses that highlight the potential for environmental harm to occur from four succinct categories associated with UHF process which include: seismicity; chemical usage; well integrity implications; and the flaring of waste gases. A summary of the main findings from this chapter are provided in the Conclusions Chapter (see section 8.1.).

The proceeding chapter (Seven - Analysis) will return to all of the issues highlighted in the conclusions to each results chapter (see sections 5.5. and 6.6.). However, there will be an integration of the theoretical concepts of ToP and eco-philosophy in order to evaluate the core issues that have been highlighted in the results chapters. Following this, Chapter Eight (Conclusions and Ways Forward) will conclude the thesis by identifying the key research findings (section 8.1.). The chapter will also outline the legislative and regulatory recommendations of the research (section 8.2.), and offer solutions to the potential for environmental harm to occur from UHF processes in the UK (section 8.3.). Finally, the thesis will conclude with highlighting the contribution to academic research and directions for further investigation (section 8.4.). The next chapter, however, will present the analysis of the research.

Chapter Seven: Analysis

7.1. **Introduction**

This chapter aims to identify issues with regards to different UHF processes which could lead to environmental harm in the UK, based on 20 interviews with key-informants. Analysis will centre around the seven key issues surrounding environmental harm identified through the literature review conducted prior to interviews, integrated with the two main theoretical components that underpin the thesis: Treadmill of Production theory, and eco-philosophy[34]. These issues will be discussed, in turn, as follows: water aquifers (7.2.), water resources (7.3.), wastewater (7.4.), seismicity (7.5.), chemicals (7.6.), well integrity (7.7.), and flaring (7.8). The conclusion (7.11.) will draw together these discussions and answer the central research question:

What do key-informants understand to be the most salient concerns regarding the potential for unconventional hydraulic fracturing to cause environmental harm in the United Kingdom?

To begin, the following section (7.2.) will consider analysis surrounding the first deductive category, the potential impact that fracking may have on water aquifers.

7.2. **Water Aquifers**

Many participants were of the view that the act of UHF is extremely unlikely to cause contamination of water aquifers. This is due primarily to the depth of target shale formations (between 1 and 3 kilometres in the UK) and the shallow existence of UK water aquifers (containing groundwaters of use to humans which are situated at

[34] There will also be two detailed sections relating the analysis directly to these two theories in section 7.9. (ToP) and section 7.10. (eco-philosophy).

100-200 metres below the earth's surface). This is consistent with academic research which suggests upwards vertical migration is unlikely to exceed certain levels (such as Davies et al. 2012, who found that the probability of onshore induced fractures extending vertically upwards at a length greater than 558 metres to be less than 1%).

However, interviews have unveiled that the act of UHF could re-activate a geological fault line (see, for example: PN13, p.194) (this occurred at the Preese Hall-1 well near Blackpool in 2011, see: Green et al. 2012) which could provide a pathway for fluid to migrate upwards. Nonetheless, the depth of UK shale means that there is sufficient geological pressure above target formations to ensure that any pathways are closed. This is demonstrated by the very fact that shale gas operators around the world are required to use some form of proppant within their fracfluid (such as sand) because this helps to ensure induced fissures remain open enabling hydrocarbons to flow out of stimulated fractures and into the well to be collected for commercial use (Heacock, 2013: 186-187). Without such proppant, geological pressure would cause induced fissures to close shortly after their creation (Jackson et al. 2013: 490).

Although upwards vertical migration, then, is realistically only a theoretical possibility, a much more prudent risk for water aquifer contamination comes from surface spills resulting from either the mis-handling of wastes or chemicals on-site, or accidents in the transportation of various substances (identified by: PN04, p.143-146). Surface spills present an opportunity for wastes or chemicals to seep into the ground thereby presenting a risk to water aquifers, groundwaters, and the surrounding surface environment (Burton Jr et al. 2014: 1683-1684; Patterson et al. 2017). Whilst TMP's and certain techniques (such as employing double-skinned tankers) could mitigate such risks, human error and accidents have led to both on-site and off-site surface spillages in the United States (Graham et al.

2015; Shrestha et al. 2017). What is more concerning from an environmental, ecological and species justice point of view, is who is responsible for the long-term monitoring of wells (see section 6.4.3.3.) and the restoration of water aquifers, if it is even possible to remedy a chemical spillage at all (Dutzik, 2013).

A second major concern with regards to the protection of water aquifers stems from the integrity of fracking wells. Operators implement MBS's in an attempt to prevent substances and geological matter from exiting the well. Although MBS's do not continue all the way down a well, they are implemented through water aquifers in order to prevent their contamination. Interviews for this research have identified three main issues relating specifically to well integrity and any potential subsequent impact on water aquifers.

The first reason is inadequate well design which could cause well integrity failure (identified by: PN06, p.155; PN09, p.152). Secondly, total well-integrity failure could lead to substances once contained within the well being able to migrate outside of the well posing a threat to groundwaters (identified by: PN05, p.148; PN08, p.149-150; PN13, p.152). Thirdly, all wells may fail over time due to the nature of concrete and steel (the constituents of well casing) which corrode, crack and deform over different timescales (PN04, p.243; PN07, p.245; PN19, p.245-246). This is a problem where substances (fracfluid, wastewaters) or geological matter, remain down a well after the well has been decommissioned and those elements could affect the integrity of the well over the long-term. This is a problem because not all produced water returns to the surface over the production lifetime of a well (Gregory et al. 2011: 183).

Despite these issues with well integrity, it must be borne in mind that all well-barriers must fail in order for well integrity to be compromised to the extent that there is a pathway for substances to contaminate a water aquifer (Jackson 2014; King and King, 2013). Therefore, it could be the case that only a small number of wells experience total-barrier failure as opposed to a single-barrier failure (identified by: PN02, p.238; PN05, p.241-242).

All of the reasons discussed in this section pose pertinent questions for policy-making where UHF is concerned. Should, for example, UHF be legislated for in the absence of a long-term well monitoring strategy? Or with the risks associated with well-integrity failure?

Table Ten (section 7.10.) provides a synopsis of how each respective eco-philosophy (anthropocentrism, biocentrism, and ecocentrism) may approach UHF in the UK, particularly in terms of legislation and regulation. It is arguable that the State's support of UHF through the passage of the *Infrastructure Act 2015* is a means to facilitate the exploitation of shale gas resources. When the points are considered above in relation to water aquifers, it is clear that such support represents an anthropocentric approach to UHF policy, where the practice is supported despite the risks associated with seismicity and well integrity, for example, and where no long-term strategy exists to monitor well integrity in the long-term.

Therefore, economic objectives are given a greater priority than associated environmental risks. ToP theory would argue that such prioritisation epitomises the treadmill metaphor in that ecological withdrawals and additions are produced as a result of capitalism and the constant strive for economic growth. Rather than viewing actions that lead to ecological withdrawals (shale gas) and additions (in this case, water aquifer contamination) as criminal activities, they are more often regarded as the 'price for progress' (Gould et al. 2008, in: Stretesky et al. 2014: 29).

7.3. **Water Resources**

The impact of UHF operations on water resources was of the least concern to participants in comparison to the other six main environmental issues under scrutiny (water aquifers, wastewater, seismicity, chemicals, well integrity, and flaring). In particular, it was often recognised that fracking would not require large quantities of water in comparison to other industrial processes. However, PN04 (p.165) did query whether utilising fresh water for UHF purposes would be the best use of that resource.

Significantly, using fresh water for UHF is an example of both an ecological withdrawal and addition. Water extracted for commercial purposes removes water from a natural environment (ecological withdrawal). Whilst some of this water will be returned to surface waters after the processing of produced waters, some water will remain underground and exist with the chemicals and deep geological matter that it will inevitably come into contact with (ecological addition).

The withdrawal of water for UHF purposes is an example of natural resources being used for commercial purposes, instead of being highly protected because of its significance to human life and the wider ecological systems that depend upon it. As Stretesky et al. (2014: 65) note, such extraction practices 'tend to produce adverse consequences for the ecological system, which to the system of capitalism is nothing but a warehouse of stored resources awaiting exploitation.' As a result, the use of fresh water for fracking can be viewed as an absolute anthropocentric endeavour.

Two participants discussed fracking in relation to water-stressed areas. PN13 (p.162) suggested that the EA may not provide an operator with a water abstraction license if there were competing needs for the water supply in that area. Additionally, PN06 (p.163) suggested that the places where fracking is most likely to occur in the UK (the North-East and the North-West) do not tend to be water-stressed areas in comparison to other areas of the UK (such as the South-East). Despite this, PN06 (p.163) was concerned with the social justice implications of the fluctuation of water prices in water-stressed regions, questioning the impact that higher water prices might have on access to clean water. However, PN16 (p.164) suggested that water resources are based on market forces, with PN14 (p.163-164) proposing that operators could source and store water for fracking at times when water is plentiful to avoid competition.

To conduct UHF, only freshwater can be used because of the salinity of seawater which could affect the integrity of a well (Nicot and Scanlon, 2012: 3585). PN04 (p.165) importantly denotes that there is a carbon cost in both the use of water (i.e. transporting water and wastewater from place to place and using high-pressure to force fracfluid down a well to fracture impermeable shale rock), and the processing of produced water back to a quality that is suitable for human consumption.

Quintessential in the analysis of water for fracking operations in the UK is the number of fracking wells and the extent to which fracking takes place. Quite simply, the larger the number of fracking wells the greater the quantity of water needed to fracture those wells. Therefore, the impact of fracking on water resources very much depends on the number of wells (and how much water is consumed per well) which is unknown at the time of submission.

7.4. **Wastewater**

Participants had much to say about wastewater and identified several different options for dealing with it. The results identified three main options that were discussed regularly which include the treatment of wastewater (section 5.4.2.), the surface storage and transportation of wastewater (section 5.4.3.), and the re-injection or otherwise underground storage of wastewater (section 5.4.4.). This section (7.4.) will regard each of these in turn.

One of the issues brought up in interviews was the ability of specialist wastewater treatment sites in the UK to deal with wastewaters produced from UHF. There are only a small number of sites that may hold the required license needed to accept fracking wastewaters because of the complex expected constituents of such wastewater (O'Donnell et al. 2018). This led some participants to the thought that fracking waste management is one of the biggest unknowns. PN04 (p.171-172), for example described this situation as an "Elephant in the room," PN08 (p.175) suggested that managing wastewater is "more of a concern" than the type and quantity of water that is originally being used, and PN13 (p.175) explained that wastewater management is "definitely a challenge at the moment and it's not been sorted."

Treatment of wastewater at a specialist facility would require the transportation of large volumes of waste from a fracking site to the required facility. This would present transportation costs, as well as the price of treatment of wastewater, and this adds to the total expenditure of specialist treatment and each total fracking process generally. PN04 (p.179) describes these financial additions as the "knock-on" effects of fracking. It could be concluded then, that the uncertainty of whether or not (and to what extent) wastewaters will be treated at specialist facilities, and the costs associated with this process, could deter operators from using such facilities in preference of other, cheaper disposal techniques. This will ultimately depend upon: the financial position of the operator; the amount, type and cost of wastewater treatment; discussions and permitting with the Environmental Regulator; all in the wake of other options that are available for wastewater disposal at any moment in time. This is, of course, stipulation compounded by a lack of legal clarity and a reactive (rather than precautionary) approach to discussions involving the management of fracking wastewaters in the UK.

In terms of environmental harm, the failure to properly treat wastewaters could have serious knock-on effects for the natural environment and ecosystems, particularly if non-treated fluid is released into natural water systems or re-injected into used wells. The exact environmental and ecological consequences of such release is impossible to quantify prior to such events taking place. Therefore, if such disposal techniques do occur, it is vital for research to take place to measure the effects. Alternatively, proper discussions on what is allowed and what is prohibited from a legal point of view needs to be much clearer and should occur before UHF takes place, rather than struggling to manage wastewaters after they have already been produced. Therefore, this thesis calls for a precautionary attitude to wastewater management rather than the current reactive approach. Quintessentially, and one of the underlying principles and rationales for this thesis, is that now (pre-UHF in the UK) is the correct time for discussing these issues, as opposed to quantifying harm that has already taken place.

In terms of eco-philosophy, permitting fracking to take place without having a distinct waste disposal plan and long-term well monitoring plan is an example of an anthropocentric approach to UHF policy, where economic objectives are prioritised over environmental risk. Due to the potentially hazardous (and therefore harmful) constituents of wastewaters from UHF processes, this thesis would promote a more biocentric or ecocentric approach to policy-making. Such an approach would either include detailed waste management plans in relevant legislation or environmental regulation or prohibit UHF until the industry and wastewater management facilities have collectively provided the government with a detailed waste management plan. Certainly, under a biocentric perspective, where the ecology and non-human animals are considered to have the same moral worth as humans (White, 2008: 11), not knowing the precise constituents of wastewater (O'Donnell et al. 2018) would be grounds to prohibit UHF practices, rather than adapting to the management of hazardous matter once it is already being produced.

With regards to the potential for re-injection of wastewaters into wells that have already been used for fracking, PN02 (p.180) explained that the *Infrastructure Act 2015* allows “any substance” to be put back into a well. PN04 (p.181-182) suggests that if more wastewater returns to the surface than predicted (and more than what an operator has permits for to store on the fracking site) then wastewater may be temporarily left (or re-introduced) into a well as a storage solution (prior to further disposal or treatment). However, PN04 (p.182) goes on to suggest that wastewater may become more contaminated with geological matter the longer it is kept in a well which makes this option a “really complicated issue.” Not only may such a solution cause issues for seismic activity and well integrity, wastewater may become more contaminated over time which makes it both more difficult and more “expensive to treat” (PN14, p.183) properly. Therefore, re-injection may be attractive to operators as it is seen to be “the cheapest option” (PN06, p.182). The unclear legality surrounding re-injection into wells (O'Donnell et al. 2018: 326) makes this situation even more complicated.

Finally, when discussing wastewater, several participants were concerned about how NORM (and other contaminants) would be dealt with (PN04, p.173-174; PN07, p.174; PN13, p.175-177; PN14, p.183). PN04 (p.173) suggests that NORM is “one of the key issues that limits the number of treatment plants that it can be dealt with” and PN14 (p.183) suggests that an underground storage solution (such as re-injection) may be “safer” than trying to “treat it on the surface or to try and transport and then treat it”. From a legislative point of view, when wastewater is treated, NORM-concentrated sludge must be disposed of at a permitted landfill site (O'Donnell et al. 2018: 325). Not only does this cost (O'Donnell et al. 2018: 325) but there may only be a small number of sites licensed to accept such waste (PN04, p.172-173; PN13, p.176-177).

There is an expectation that fracking will produce large quantities of flow-back fluid and produced waters (which will vary from site to site). The *ad hoc* approach to dealing with such wastewaters can be seen as a typical example of state-corporate failure to appropriately reduce ecological disorganisation as much as possible. Ultimately, wastewater will be treated according to the economic viability of different options at the time that wastewater needs to be dealt with. This is a perfect example of the relationship between the ecology and the economy (essential to ToP theory) where environmental harm is a necessary requirement for successfully producing hydrocarbons.

7.5. **Seismicity**

When discussing the potential implications that fracking activities might have for seismicity, participants largely focussed on five different issues. This section will consider each of these in turn:

- The effect that pre-existing faults may have on seismicity;
- The effect that re-injecting wastewaters into existing (re-use) or abandoned wells (disposal) has on seismicity;
- The regulation (particularly the TLM system) in place surrounding seismicity from fracking activities;
- The potential for property or infrastructure damage, and;
- The effect that seismicity from fracking may have on the integrity of wells (existing and/or abandoned).

When discussing the activation of fault lines, participants nearly always used the seismic events at Preese Hall in 2011 as an example of induced seismic activity that affected a geological fault plane. This is significant because Preese Hall (at the time of submission) is the only horizontal well that has been hydraulically fractured onshore in the UK (Gibbons et al. 2016: 4). The resulting earthquake activity as a result of operations at Preese Hall 'was caused by direct fluid injection into an adjacent fault zone… (which) reduced the normal stress on the fault, causing it to fail repeatedly in a series of small earthquakes' (Green et al. 2012: 2). However, (and similar to arguments concerning water aquifers), whilst fracking may produce seismic activity, it is expected that such movement will be of very low magnitude (PN13, p.194) and that the geological pressure conditions that exist above fracture locations will constantly force pathways to close.

The EA (2016: 44-47) will permit the re-injection of produced waters for disposal purposes (with the required permit) but will not authorise flow-back fluid in the same manner. Both types of wastewater, however, may be re-injected for production purposes (EA, 2016: 44-47).

According to Ellsworth (2013: 1) 'it has long been understood that earthquakes can be induced by… injection of fluids into underground formations,' the largest of which recorded in the United States (attributed directly to fracking) is 5.6 on the Richter scale (Ellsworth et al. 2015). Whilst participants did not express great concern with regards to the impact that seismicity from fracking might have (for example, PN07, p.196-197; PN12, p.197-198; PN18, p.205), some participants did suggest that the re-injection of fluid for disposal purposes is a problem (such as PN07, p.196-197). However, interviews did not sincerely reveal what these problems were, other than the potential for such activity to damage property and infrastructure (PN06, p.203-204; PN07, p.203; PN12, p.203; PN19, p.199), and implications for well integrity (PN05, p.204-205; PN14, p.206; PN18, p.205).

In terms of property and infrastructure damage, participants suggested that the foundations of buildings may be affected (PN19, p.199), and that there may be additional financial costs (PN06, p.203-204) in terms of repair and maintenance for roads and buildings that are affected. Finally, participants seemed very aware about the regulations in place to monitor seismicity (for example: PN05, p.200; PN07, p.200; PN09, p.201) (such as the TLM system), which may have contributed to the low-concern that participants showed towards the issue of seismicity.

The theoretical concepts underlining this thesis could shed some light on the significance of anthropocentrically induced earthquakes from fracking processes. Seismic events produced from fracking are certainly an ecological addition because, simply, they are the result of a fracking process which is additional to seismicity that would have otherwise occurred. Although the UK experiences frequent low-magnitude earthquakes (BGS, 2018), those induced as a result of the re-injection of wastewater have the potential to be of greater magnitude than those that occur naturally (Ellsworth et al. 2015; McGarr et al. 2015). Therefore, a decision has to be made on whether to allow fracking (and subsequent earthquakes) in the light of potential property and infrastructure damage and risks to public health.

Permitting fracking of the type that may cause low-level earthquakes can be seen as an ecocentric approach to fracking, ecocentrism being the philosophy that ‘refuses to place humanity either above or below the rest of nature’ (White, 2008: 11). By developing the TLM system, whereby production is immediately suspended following a 0.5+ magnitude earthquake (DECC, 2013) the government (and industry) can be seen to be adopting an ecocentric approach where seismicity is concerned. An anthropocentric approach would arguably permit fracking regardless of its effects on seismicity because the perceived moral superiority of humans would prioritise hydrocarbon production for human consumption over any potential environmental damage.

However, the TLM system can also be seen to be a reactive approach to seismic monitoring. If, for example, an operator disposed of produced water in a former fracking well (a process which is associated with high levels of seismicity) causing a magnitude 4 (Richter scale) earthquake, although the TLM system would suspend operations, the resulting damage may have already occurred. Therefore, if a truly ecocentric or biocentric approach to regulating fracking was preferred, it is arguable that both the government and the EA would not condone the disposal of any wastewaters in a fracking well due to the associated risks discussed in this section (potential effects on well integrity; property and infrastructure damage; and risks to public health).

7.6. **Chemicals**

Interviews revealed that it is very difficult to predict which chemicals will be used for fracking because usage will vary from site to site and from operator to operator (PN05, p.213). The main reason for this is that shale is not a consistent rock. Shale's impermeable properties require the rock to be split open in order to release the hydrocarbons trapped within. As Speight (2013: 5) recognises: 'each shale formation has different geological characteristics that affect the way gas can be produced, the technologies needed, and the economics of production.'

There are many different chemicals that can be used to help aid this process. The table produced by Stuart et al. (2014) (see Appendix Thirteen) gives a detailed list of substances that may be used in fracfluid, highlighting three substances that have been used in the UK for shale gas fracking. These three substances (Hydrochloric Acid, Polyacrylamide and Glutaraldehyde Biocide) are three of the four main substances that participants also spoke about in relation to the substances that they might expect to be used within fracfluid (see section 6.3.2.). These can be used for many different purposes but are mainly concerned with initiating cracks in the shale rock (such as Hydrochloric Acid), minimising friction so less pressure is required to initiate cracks (a friction-reducer such as Polyacrylamide), and minimising the growth of bacteria that can be damaging for the well (such as biocides) (Stuart et al. 2014; PN13, p.216; PN18, p.218).

Although chemicals are a necessary requirement for the successful production of shale gas, participants identified issues with:

1. The trial and error nature of chemical usage;
2. Transporting chemicals;
3. The impact of chemical exposure on public health; and,
4. Concerns around commercial confidentiality.

Chemicals can be seen as both an ecological withdrawal (using resources and energy to create chemicals) and an ecological addition (adding chemicals to the underground geology). This thesis has identified several ways in which groundwaters and water aquifers could become contaminated with chemicals and other elements (see sections 5.2., 6.3., and 6.4. in particular). Chemicals are a part of this because even if the EA condones the use of what they consider to be non-hazardous chemicals in the concentrations used, chemicals still play a part in the make-up of wastewaters which are expected to contain harmful matter that exists within sub-surface geology (such as NORM's). PN05 (p.274) suggested that:

PN05: "*there's probably an element of trial and error, um, but the companies will have characterised the geology as fully as they think they need to then make those judgements accordingly*."

Such a reactive *trial and error* approach to chemical usage is clearly representative of an anthropocentric approach to hydrocarbon production. Although the use of only non-hazardous chemicals could be regarded as an ecocentric philosophy where there is an environmental-economic trade-off, the ability for chemicals and other geological matter to be either disposed of down a well (highlighting ecosystem concerns and potential problems for future generations of humans who are unlikely to know the exact whereabouts of such chemicals), or transported to a treatment facility (where road accidents can occur) highlights the anthropocentric focus on using chemicals to produce hydrocarbons in the short-term with little regard for the potential long-term ecological and public health impacts of such usage.

In terms of transporting chemicals and wastewaters from fracking production processes, PN12 in particular suggested that there are two major ecological additions. Firstly, there are risks to humans in the transportation of chemicals and in the handling of chemicals on-site (PN12, p.223). Secondly, he suggests that the diesel fumes from lorries are a considerable source of harm in terms of air pollution (PN12, p.223). This ties in neatly with one of the main premises of ToP theory with regards to ecological additions. As Stretesky et al. (2014: 67) state:

> 'production generates ecological additions that often take the form of pollution, and promotes ecological disorganization. Not all forms of pollution are regulated, however, and of those releases that are, an even smaller proportion are treated as criminal.'

Neither the release of diesel fumes from industrial lorries, the spilling of chemicals (on or off site), the disposal of produced water in a fracking well, nor the treatment of contaminated wastewater at treatment facilities (all of which can be seen as harmful ecological additions) are deemed to be criminal acts. These are all ecological additions that are by-products of, and are often central to, the production of gas from shale formations. ToP theory would suggest that the significance and centrality of such pollution to production is the reason that these forms of pollution are considered legal by the State and regulatory bodies. As Stretesky et al. (2014: 69) suggest: 'it is important to examine why some ecological additions become criminalized while others do not. Ecological additions are inclined to be tolerated when they are central to capitalist production.'

Finally, participants often raised the issue of commercial confidentiality where fracking chemicals were concerned (PN06, p.227; PN09, p.228; PN14, p.229; PN18, p.230). At the time of submission, operators must disclose the contents of fracfluid to the Environmental Regulator, but public disclosure is only voluntary (Hawkins, 2015: 18). The issue here is that different operators may wish to gain a "competitive advantage" (PN18, p.230) once they have found a chemical formula that works well in a particular location, therefore choosing to guard (rather than share) their successful formula.

Such competition is a critical component to ToP theory because 'to make a profit and prevail over competitors, firms constantly find technologies that increase production' (Greife and Stretesky, 2013: 151). Therefore, producing an effective fracfluid (aided by commercial confidentiality) may enable an operator to gain a market advantage over other competitors. This is instead of the industry collaborating and sharing information on the chemical composition of fracfluid communicating which formulas have worked best (in terms of, for example, preventing well integrity issues) which could work to reduce environmental harm.

7.7. **Well Integrity**

The primary reason participants gave to suggest fracking would have very little effect on well integrity was the proper design and construction of wells with multiple strings of casing to protect the well by containing contaminants (PN01, p.234; PN05, p.234). The main premise was that a single WBF does not necessarily lead to substances leaking out of the well. Only a full WIF (where all barriers fail) will lead to a leak. This is supported by academic research (King and King, 2013) and is well summarised by PN14 (p.235), a water consultant, who states that:

PN14: "*some of the studies cite a number of well failure's but that doesn't necessarily mean that they leaked into the environment because it's one failure within a multiple barrier system. So, one layer could have failed but the other two might have stayed intact.*"

However, three main issues arose in interviews with regards to the potential for fracking to have a negative effect on well integrity. These issues included: the number of well failures; the thought that all wells may fail over time; and other issues surrounding the long-term monitoring of wells (see section 6.4.3.).

A number of participants gave different percentages for the numbers of wells that would fail over different time periods (for example, PN02, p.238 suggested 5% of wells will lose integrity within the first year, whereas PN03, p.238 suggested 34% will fail within the first five years). This somewhat corresponds to academic research on well failure in the United Sates. Jackson et al.'s (2014) literature review of different studies of well failure frequency suggest that well failure rates (of both WBF and WIF) are between 2.6%-6.3%. Therefore, whilst unconventional wells may be up to six times more likely than conventional wells to exhibit well failure (Ingraffea et al. 2014), the overall percentage of full WIF is likely to be a very low (albeit currently unknown) percentage.

In the UK, only one well (at Preese Hall, near Blackpool) has been subject to onshore UHF (in 2011). Shortly after fluid injection, wellbore deformation was discovered, but later tests demonstrated that the well did not exhibit full WIF (Green et al. 2012: 11). This suggests that well integrity issues are a concern in the UK context.

Again, this can be related to eco-philosophy. The decision to legally permit UHF in the wake of potential well integrity issues (which have the ability to directly impact the natural environment and cause ecological disorganisation), is a decision that has an element of risk, even if the probability of full WIF is statistically low (Jackson et al. 2014). Whilst the impact of full WIF would irrefutably depend on the extent of shale gas operations in the UK, even a small number of WIF's could cause significant ecological harm. For example, the UK government originally estimated that 155 shale gas wells would be in operation in 2025 (Hayhurst, 2018). If this were to become reality, taking the lowest value found by Jackson et al. (2014) of 2.6% (of 155 wells), 4.03 wells are likely to experience WBF or WIF in the UK. Given a more extensive shale gas industry in the UK as suggested by the Institute of Directors (2013) of 4,000 wells by 2032, 104 wells (at 2.6%) would exhibit WBF or WIF. Although WBF does not necessarily result in full WIF (King and King, 2013), WBF is a concern in terms of seismic activity (Green et al. 2012), but also for the integrity of the well in the long-term.

Following on from this, some participants suggested that all wells will fail over time (PN04, p.243; PN07, p.245; PN19, p.245-246) which raises a very important concern regarding the responsibility for wells post-decommissioning. As PN04 (p.244-245) denotes:

PN04: "*once these wells have been abandoned who carries on looking to see whether they are still OK?*"

Although wells may not demonstrate full WIF immediately, Miyazaki (2009, in: Boothroyd et al. 2016: 462) states that 'overtime it is expected that the condition of abandoned wells will deteriorate.' As the ownership of 53% of conventional UK wells is currently unclear (Davies et al. 2014: 247), coupled with the fact that there are no onshore UHF wells in the UK (let alone any of a significant age to research the extent of deterioration) it is currently unknown how unconventional wells in the UK will deteriorate over time, and whether this will have an impact on the environment.

Although there is currently no monitoring of abandoned wells in the UK (Boothroyd et al. 2016: 462), Davies et al. (2014) found higher concentrations of soil gas methane above abandoned (conventional) oil and gas wells in the UK. This suggests that the environmental impact of oil and gas development does not disappear when a well is decommissioned. Given that unconventional wells are more likely to exhibit well failure than conventional wells (Ingraffea et al. 2014) it is likely that the environmental impact will be greater in decommissioned unconventional wells.

Such environmental impact not only constitutes ecological additions, but, from and eco-philosophical point of view, represents a purely anthropocentric approach to oil and gas policy-making in the UK. This is because, if the environmental impact from decommissioned wells is unknown (but likely to be negative, as in conventional wells), the decision to proceed with UHF is akin to an anthropocentric mode of decision-making. As Halsey and White (1998: 50) explain:

> 'Decisions concerning the environment are made according to which outcomes will best secure narrowly defined economic outcomes. Usually such decisions are made at the expense of securing long-term stability of social and ecological systems.'

This thesis argues that now (pre-production stage of UHF in the UK) is the right time to be debating these issues (i.e. before any negative environmental effects of UHF can emerge). This is because it is better, in terms of preventing environmental harm, to discuss (and either try to manage environmental harm, or to prohibit the practice to prevent environmental harm) rather than to undertake an activity that is likely to create a number of environmental harms. This parallels the precautionary principle of environmental law which ‘requires states to take action where a risk to human health or the environment exists, but there is evidential uncertainty as to the existence or extent (magnitude) of the risk’ (Wolf and Stanley, 2014: 16). There is, undeniably, evidential uncertainty as to the impact of UHF on well integrity, particularly in relation to UHF’s impact on seismicity and the long-term environmental effects of decommissioned wells (and producing wells). As a result, the state-corporate support of UHF in the UK (particularly in the face of overwhelming public opposition) is clearly an example of the dominance of anthropocentric decision-making (preferred over ecocentric or biocentric perspectives) and demonstrates the power of the treadmill of production.

The support for onshore UHF in the wake of the decline of North Sea oil and gas exploration and production (Aleklett et al. 2010: 9) in particular, demonstrates the persistence of the treadmill and the need to exploit natural resources in order to continue to fuel the treadmill. Gould et al. (2008: 13) suggest that the post-Second World War era promised ‘unlimited energy… and newly accessible mineral and other extractive resources (particularly petroleum) (which) led to social and political inattention to ecological limits and unthinking support for unlimited economic expansion’. Now it has been realised that such resources are in fact, limited and non-renewable, more extreme forms of energy extraction (Short et al. 2015) such as UHF, are being supported by state-corporate actors in order to keep the treadmill running. This can be seen by the passing of the *Infrastructure Act 2015* which effectively supports the production of natural gas in the UK. This is typical of the treadmill where ‘acts central to production will tend to take legal precedent over those central to ecology’ (Stretesky et al. 2014: 147).

7.8. **Flaring**

Flaring (i.e. burning waste gas into the atmosphere) is a necessity when drilling a natural gas well because the first gas that becomes available is known as “dirty gas” (PN16, p.249-250) or ‘impure natural gas’ (Speight, 2013: 156; World Bank, 2002: 9). The National Grid only accepts natural gas of a certain quality and, therefore, dirty gas is unlikely to be suitable because it contains a lot of the products that are used to create and fracture the well (PN16, p.249-250) (and other geological matter from within the well). Despite this, some participants suggested that flaring would only be a very short-lived endeavour (PN05, p.251) due to operators wanting to keep as much gas as possible because natural gas is, after all, the product that is being sought after (PN05, p.251; PN09, p.251; PN17, p.253).

Many participants were uncertain as to the impact of flaring from an environmental point of view, questioning the properties of the matter that is expected to be flared in the initial stages of drilling a well. For example, both PN03 (p.254) and PN04 (p.254-255) discussed the impact of VOC’s and benzene (from flaring), and its potential impact on those living in close proximity to fracking sites (PN04, p.254-255). Others discussed the environmental harms associated with the release of $C0^2$ (PN07, p.256), the possibility of venting (the direct release of dirty gas, unburnt) (PN03, p.254; PN07, p.256), and the visual implications of having an open flare tip (PN16, p.255; PN18, p.258).

Despite these implications, there are options to mitigate against the visual and environmental impacts of flaring. PN16 (p.255) suggests that flare boxes significantly reduce the visual impact of having a burning open flare. Additionally, the future may bring ‘green completions’ (DECC, 2014b: 2) such as methods of carbon capture and storage (CCS) or the converting of flare gas into fuel gas (Zadakbar et al. 2008). Such options would help to reduce the short-term emissions problems associated with flaring waste gases from UHF processes.

Flaring (and venting), however, are perfect examples of ecological additions associated with the transformation of natural resources into consumable energy. Whilst, technological innovations such as CCS can be seen as measures to reduce the environmental impact of production processes, oil and gas production in particular is not a perfectly efficient process. For example, when discussing UHF PN16 (p.186) (an oil and gas professional) notes that operations “are never perfect. Bottom-line. There is no oil platform that doesn’t drop a few drops of oil in the sea. Um, we are not perfect in our operations.” This ties in with Schnaiberg’s (1980) treadmill notion that ecological withdrawals and ecological additions are essential interactions between the economy and the ecology. As Stretesky et al. (2014: 67-68) suggest:

> ‘Economic production must create pollution because production cannot be perfectly efficient, and as the laws of thermodynamics indicate, production impacts the transformation of matter by generating entropy. Moreover, since capitalism requires continuous economic expansion, it has a tendency to constantly promote the production of ecological additions and entropy. These outcomes are not easily solved by technology, since technological innovations tend to be unable to override the effects of constantly expanding consumption and production linked to capitalism.’

Therefore, the release of harmful matter at different stages of UHF (whether it be through the flaring of dirty gas, pipeline leaks, truck accidents, or the re-injection of produced water as a waste disposal method), are all examples of ecological additions associated with an UHF process that can never be perfectly efficient.

Where hydrocarbon transformation into consumable energy is concerned, the production of oil and gas must create pollution because of the laws of thermodynamics (energy cannot be created or destroyed, only transformed and, when transformed in production, takes on a less organised form, see: Stretesky et al. 2014: 20). As the treadmill requires the constant expansion of production under capitalism, any gains in efficiency ‘are bound to be offset eventually by output expansion’ (Gould et al. 2008: 81). Therefore, ‘reducing the levels of ecological withdrawals and additions per unit of production attains environmental gains only when levels of total output are kept steady’ (Gould et al. 2008: 81). From this, it could be suggested that any level of UHF in the UK will create both ecological withdrawals and additions which are generated by transforming energy, through production, into less organised forms (consumable energy or pollution).

7.9. **Implications of Treadmill of Production Theory for Analysis**

ToP theory centres on the two laws of thermodynamics and both of these principles are directly relevant to the harms created by UHF. First is the conservation of energy principle, the thought that ‘*energy cannot be created or destroyed, only transformed*’ (Stretesky et al. 2014: 20, emphasis in original). The principle aim of UHF is to collect natural gas stored within impermeable formations (a form of ecological withdrawal). Through this process, gas is collected (rather than created) and cannot be destroyed (it either escapes as a fugitive emission or is consumed and waste gases are released). Therefore, the gas is only transformed.

The second law of thermodynamics concerns entropy which ‘refers to the capacity for rearrangement’ (McKinney, 2012: 296). In relation to ToP, ‘as energy is transformed in production it takes on less organised forms’ (Stretesky et al. 2014: 20). The transformation of shale gas into a disposable product produces $C0^2$ when consumed. Similarly, the burning of dirty gas through flaring transforms natural gas into a less organised form through the release of GHG emissions (these are forms of ecological additions).

Table Ten (below) details the potential factors that could lead to ecological withdrawals and additions as a result of UHF processes in the UK identified by this thesis. Because of the laws of thermodynamics, ecological disorganisation (where energy is transformed into less organised forms becoming disorganised) is created by these withdrawals and additions:

Category	ToP - Ecological Withdrawal	ToP – Ecological Addition
Water Aquifers	- The withdrawal of water from aquifers for use in fracfluid is an ecological withdrawal.	- Human error from transportation accidents, or spillages on a fracking site could lead to water aquifer contamination. - Full WIF presents a pathway for substances to contaminate a water aquifer. - Any chemical contamination of an aquifer is an ecological addition.
Water Resources	- Extracting freshwater for hydraulic fracturing production purposes.	- There is a carbon cost involved in both extracting and transporting fresh water to be used in hydraulic fracturing, and in the treatment of produced waters.
Wastewater	N/A	- Wastewaters are an additional by-product of UHF processes. These could be potentially harmful if re-injected for disposal purposes, or if they come into contact with humans or the wider environment (for example, through accidental spillages).
Seismicity	N/A	- Earthquakes created by fracking are additional to those that would have otherwise occurred.
Chemical Usage	- There are environmental and carbon costs associated with both the creation and transportation of chemicals for UHF purposes.	- Transporting chemicals is likely to result in air pollution from diesel emissions produced by trucks. - Human error from transportation accidents, or spillages on a fracking site could lead to the addition of chemicals and wastewater in the environment.
Well Integrity	N/A	- Full WIF presents a pathway for substances to contaminate a water aquifer. Whilst percentages of well integrity failure in oil and gas operations are low, pollution has occurred as a result of WIF, which is a clear ecological addition.
Flaring	- UHF extracts shale gas. Burning the gas once contained within a geological formation is an example of an ecological withdrawal.	- Flaring gas releases $C0^2$ into the atmosphere. Therefore, flaring is an ecological addition because the $C0^2$ would not have been released without the original extraction of the gas for UHF purposes.

Table Ten: *The Ecological Withdrawals and Ecological Additions Identified in the Research*.

In relation to the t*readmill* notion, fracking in a UK context can be interpreted as enabling the fossil-fuel treadmill to keep running (and accelerating) as UHF is a means for expanding the production of fossil fuels. This enables the accumulation of capital which is essential under capitalism to constantly strive for profits which keeps the treadmill accelerating. Production must increase in order for investments in new methods of extraction (such as fracking) to pay-off (Long et al. 2014: 266).

Some authors refer to this situation as *extreme energy extraction* (Hulme and Short, 2014; Lloyd-Davies, 2013; Mobbs, 2014; Short et al. 2015). Fracking is a perfect example of this because it refers to both an extreme resource (shale gas derived from impermeable strata) and an extreme extraction technique (horizontal hydraulic fracturing at high pressure). Such extreme methods are required under the treadmill philosophy because production needs to increase year on year in order for profit to increase (and to satisfy shareholders who invest capital). Therefore, if conventional methods of energy extraction (such as conventional hydraulic fracturing, or North Sea hydrocarbon production) are in decline, States will seek more extreme methods of energy extraction in order to continue to facilitate production.

Furthermore, in order to keep down production costs (to generate more profit, particularly in the face of declining conventional extraction, such as North Sea production) the treadmill theory predicts other occurrences such as the displacement of labour by technological advancement and chemically-assisted production (Long et al. 2014: 265-266). This can be seen through fracking processes because very little labour is needed once a well is producing gas creating a *boom-and-bust* cycle (Brown and Swanson, 2003; Hirsch et al. 2017).

Such production not only creates ecological disorganisation, but the displacement of workers with technology creates social disorganisation. According to Stretesky et al. (2014: 92-93) ‘technological advances that rely on processes that create ecological disorganisation tend to decrease the need for labour and therefore increase social disorganisation and destroy ecosystems.’ Technological advances identified in this thesis (such as green completions, CCS or dry hydraulic fracturing) are further examples of how technological advancement can increase production and reduce production costs. However, the treadmill philosophy predicts that whilst technological advancement can have a short-term positive impact in terms of the reduction of ecological destruction per unit, because production and profit must continually increase, ecological disorganisation must increase simultaneously. Therefore, production will always produce social and ecological disorganisation because production can never be perfectly efficient (PN16, p.186; Stretesky et al. 2014: 67). Additionally, social disorganisation mirrors ecological disorganisation through the displacement of labour, and the increase in crime levels that are associated with the production of hydrocarbons (Komarek, 2014; O’Connor, 2017; Stretesky et al. 2018b).

7.10 **<u>Implications of Eco-Philosophy for Analysis</u>**

Eco-philosophy provides a unique vantagepoint from which to view human interactions with ecological systems amalgamating environmental harm with policy-making and economic objectives. For example, anthropocentrism would view environmental harm as a necessary component to economic production which is facilitated by legislation and regulation. A biocentric perspective juxtaposes this position, and views environmental harm as unquestionably damaging to ecosystemic well-being. Therefore, economic production is denied under biocentrism by laws and regulations which are designed to prioritise ecological health over any luxuries that would be provided by human production.

White (2008: 12, drawing from Halsey and White, 1998) lays out three tables that consider the extent to which each eco-philosophy may view the practice of clear-felling old-growth forests. The following Table (Eleven, below) uses this technique in respect of how each eco-philosophy might view the practice of UHF in the UK:

Anthropocentrism An anthropocentric perspective would view UHF instrumentally, as a production method that satisfies the immediate demands of humans in terms of economic priorities (i.e. creating jobs and contributing towards economic growth) as well as providing consumable volumes of natural gas that are necessary in many industrial processes, as well as in people's day-to-day lives. Economically, anthropocentrism requires that shale gas be exploited for its commercial worth and production operations should be those that incur the lowest costs to producers. The aim of legislation is to facilitate extraction and also to deal with conflict between different operators. Legislation would also prohibit over-extraction so shale gas can be produced for as long as possible.
Biocentrism A biocentric view would perceive shale formations as having intrinsic worth and value (as a natural part of the geological make-up of the earth, and as a place for the organisms that reside within), which is greater than any value that can be placed on shale formations by humans. Furthermore, such geological strata contain matter that, if released through UHF would contribute to ecological disorganisation. Legislation would therefore be aimed at preserving shale formations, and also other ecological sites that could be adversely affected by UHF (such as water aquifers and the atmosphere as a result of flaring and diesel emissions). Consequently, legislation would act to prevent UHF and to protect the natural environment, rather than facilitating production.
Ecocentrism Ecocentrism would attempt to strike a balance between the human uses for shale gas, and the long-term survival of humans, non-human species and the wider ecology. Ecocentrism would advocate methods of production that honour eco-systemic health (such as CCS or other green completions) over any short-term economic demands to extract shale gas quickly. Legislation, therefore would centre around facilitating the greenest possible forms of energy creation (such as renewable energy), and permit UHF only in exceptional cases where shale gas is valued for human survival (such as for some essential industries). Legislation would not be influenced by any anthropocentric goals concerning job creation or wealth accumulation.

Table Eleven: *Approaches to UHF in the UK from the Three Different Perspectives Within Eco-Philosophy*.

By passing the *Infrastructure Act 2015* the UK government facilitated the production of hydrocarbons including permitting the technique of UHF. This is a clear representation of anthropocentrism under eco-philosophy. The environmental harms covered in this thesis can be viewed as necessary externalities of production. In this case then, production has clearly been prioritised over human and ecological health.

7.11. **Conclusion**

This chapter has integrated the results of interviews regarding different aspects of the UHF process with the two theoretical concepts underpinning this thesis (ToP theory and eco-philosophy). It has identified the main areas where environmental harm could occur in each of the seven categories considered (water aquifers, water resources, wastewater, seismicity, chemical usage, well integrity, and flaring) according to participants and academic literature.

The aim of this chapter was to answer the central research question of the thesis:

What do key-informants understand to be the most salient concerns regarding the potential for unconventional hydraulic fracturing to cause environmental harm in the United Kingdom?

What this chapter has shown is that this research question is highly complex because there are a multitude of ways that environmental harm could be created as a result of different UHF processes. There is not one central concern, but several different concerns. Effectively, the results (Chapters 5 and 6) together with this analysis chapter have answered the central research question in a very long and complex way, owing to the multitude of processes that are necessary to perform UHF. This is further complicated by the realisation that UHF is not yet at a production stage in the UK, and also by the fact that UHF is likely to vary significantly from place to place depending upon the underground geology and the operator.

However, despite these complications, the theoretical underpinnings of this research have undoubtedly provided an explanation as to why certain actors (largely the State and different fracking companies) support and facilitate the production of hydrocarbons using techniques of UHF. The treadmill explains why extreme energy extraction techniques are utilised to increase production at the expense of ecological degradation. Furthermore, eco-philosophy provides contrasting perspectives from which to view decisions that are made regarding the use of UHF technology. The prioritisation of consumable energy for human desire at the expense of environmental harm clearly demonstrates an anthropocentric approach to resource use (and abuse).

The following chapter will conclude the research by outlining the central findings of the thesis. This will be displayed via a table in section 8.1. Section 8.2. will discuss the legislative and regulatory recommendations of the research. Section 8.3. will offer solutions, and section 8.4. will outline the distinct contribution of the research to academic knowledge (highlighting originality) and will also discuss important areas for further research.

Chapter Eight: Conclusions and Ways Forward

8.1. <u>Key Research Findings</u>

The central research question for the thesis was as follows:

What do key-informants understand to be the most salient concerns regarding the potential for unconventional hydraulic fracturing to cause environmental harm in the United Kingdom?

As the results (Chapters Five and Six) and analysis (Chapter Seven) have shown, there are many different ways in which environmental harm may occur as a result of UHF processes in the UK. For simplicity, these findings are displayed in a concise way in the following table and, together, provide an answer to the central research question:

<table>
<tr><td>Water Aquifers

Fracking is extremely unlikely to enable upwards vertical migration of substances from a deep shale formation to shallow water aquifers.
Geological pressure is sufficient to prevent upwards vertical migration, even if a fault line is activated.
Traffic accidents involving trucks transporting chemicals or wastes could result in surface spillages leading to water aquifer contamination.
Although MBS's are designed to prevent contamination, full WIF presents a pathway for substances to contaminate a water aquifer.
</td></tr>
<tr><td>Water Resources

Relative to other industrial processes fracking will have little impact on water resources in the UK.
The impact of fracking on UK water resources is unknown due to the infancy of the UHF industry.
</td></tr>
</table>

• There is a carbon cost in the energy used in transporting water and wastewater and in treating produced water. There is also a carbon cost in using water at pressure to fracture shale rock.
Wastewater • Wastewater treatment is an “Elephant in the room” (PN04) that has not yet properly been sorted. • It is unknown whether specialist wastewater treatment facilities in the UK will have the capacity to deal with fracking wastewaters. • The treatment of wastewater depends on several different factors and is complicated by a lack of legal clarity. • The legality surrounding wastewater re-injection is unclear but is regarded as a cheaper (and therefore more attractive) wastewater solution than expensive specialist treatment.
Seismicity • The activation of geological fault lines presents a low risk of fluid migration due to sub-surface geological pressure conditions which force induced pathways to close. • Seismicity could cause damage to property and infrastructure. • Participants were largely complimentary of the TLM system and believed this was a useful regulatory measure to control seismicity. • Seismicity may have a negative effect on a well’s (or surrounding wells) integrity.
Chemicals • Chemicals used in fracking operations will vary from site to site depending on the operator and the underlying geology. However, three quintessential components of fracfluid in the UK are likely to be: Hydrochloric Acid; Polyacrylamide; and Biocide (in concentrated form). • Establishing a successful chemical formula may be a case of trial and error.

- Transporting chemicals could result in harmful spills of either chemicals and/or wastewater which could have consequences for both humans and the wider ecology.
- Transporting chemicals also requires air pollution in the form of diesel emissions.

Well Integrity

- A single WBF does not mean a well has experienced full WIF because all wells are cased with MBS's.
- Full WIF will provide a pathway for fracfluid or wastewaters to enter groundwater.
- It is possible that all wells may experience full WIF given a long enough timescale because steel rusts and concrete erodes (well barriers are constructed out of steel and concrete).
- Responsibility for the long-term monitoring of wells in the UK is unknown.

Flaring

- Flaring must take place in the initial stages of UHF because the first gas to enter the wellbore when a well is drilled (or hydraulically fractured) is known as *dirty gas* which is likely to be of insufficient quality to be accepted by the National Grid.
- Some participants discussed the impact of VOC's and benzene (from flaring), and its potential impact on those living in close proximity to fracking sites.
- Flaring impure natural gas (converting it to $C0^2$) is an ecological addition in the form of air pollution.
- Venting (the direct release of dirty gas, unburnt) is less desirable than flaring because of the constituents of dirty gas.
- An open flare tip could have visual implications, but there are methods to combat this such as using a flare box or other green completions.

Table Twelve: *Concise Findings*.

8.2. **Recommendations for Legislative and Regulatory Changes**

The fracking operations that occurred at Preese Hall in 2011 have resulted in a series of legislative and regulatory controls on UHF processes. This includes the *Infrastructure Act 2015* and the involvement of regulators (the EA and HSE) who are tasked with managing the permitting process where UHF operations are concerned. It is undeniable that these controls make environmental harm much less likely than if there were no controls at all.

However, this thesis has made it clear that there are several areas where environmental harm may occur as a result of fracking processes in the UK as a result of interviews with key-informants. Similarly, it has also demonstrated that many areas of the current regulatory and legislative system are inadequate in preventing environmental harm. The following table demonstrates the weaknesses of the current approach to managing UHF operations, and also suggests recommendations for eliminating or curtailing environmental harm, based on the issues raised by key-informants to this research.

Water Aquifers
Current Controls - S.50(4A) of the *IA 2015* prohibits UHF occurring at depths of less than 1,000 metres below surface level. **Recommendations** - **No recommendations**. This depth is sufficient in preventing the upward vertical migration of fluids from the site of UHF to a water aquifer (see section 5.2.2.2.).
Water Resources
Current Controls - S.50(4A) of the *IA 2015* prohibits UHF taking place within groundwater protection areas.

-S.50(4A) of the *IA 2015* also requires the environmental regulator to give an operator an environmental permit requiring compliance to a Waste Management Plan which ensures the level of methane in groundwater will be monitored in the 12-month period before UHF begins.

Recommendations

- **No recommendations**. This protects groundwater in valuable groundwater protection areas.
- **No recommendations**. This requirement will ensure that levels of methane can be monitored before, during, and after UHF in order to ascertain the effect (if any) of production on methane levels in groundwater.

Wastewaters

Current Controls

- The *IA 2015* does not include any legislative measures to deal with the wastes produced from UHF operations.
- The *IA 2015* does not require any long-term management of decommissioned wells.

Recommendations

- **Three recommendations**.

1. The government should seek advice, consult, and amend the *IA 2015* in order to make it clear what the plan is for managing wastes produced from UHF.
2. The Environmental Regulator should also state clearly how it intends to permit flow-back and produced waters which are inevitable by-products of UHF.
3. Key-informants revealed that properly disposing of wastes at wastewater treatment facilities is an expensive process. This is supported by recent work from O'Donnell et al. (2018). However, expense should not lead to more convenient (and more environmentally harmful) disposal methods (such as re-injection for storage purposes, or releasing into natural water systems). Operators wishing to conduct UHF should liaise with specialist treatment facilities to manage their wastes, or should (perhaps with the help of government and industry) work towards investing in the building of more treatment sites that are capable of treating fracking wastes. If operators cannot find (or invest in) a treatment facility, then fracking should be prohibited on the basis of the precautionary principle of environmental law. This states that action should be

taken 'where a risk to human health or the environment exists, but there is evidential uncertainty as to the existence or extent (magnitude) of the risk' (Wolf and Stanley, 2014: 16). Accordingly, there is evidential uncertainty with all disposal options (such as re-injection and untreated or partially treated release into natural water systems) other than proper and specialist disposal at a competent wastewater treatment facility.
Seismicity **<u>Current Controls</u>** - Seismic activity is controlled well by the TLM system that prevents fracking from continuing if an earthquake of 0.5+ Richter scale magnitude occurs (resulting in a red light, see Appendix Twelve). **<u>Recommendations</u>** - **No recommendations**. However, it is important to in no way relax this regulatory measure (TLM system), because higher rates of seismicity may affect well integrity (of the well, and/or nearby wells). Significant seismicity may also pose minor risks to public health and infrastructure damage.
Chemicals **<u>Current Controls</u>** - S.50(4B) of the *IA 2015* suggests that an operation only constitutes fracking if it involves the injection of more than 1,000 cubic metres of fluid at each stage (or more than 10,000 cubic metres in total). - Chemicals to be used in UHF must be approved by the EA who only permit the use of non-hazardous substances (Jacobsen et al. 2015: 30). - S.44(1) of the *IA 2015* enables the passing through, keeping, using, or removing of any substance put into deep-level land. - Whilst the UKOOG (2013c: 29) recommend that operators disclose the chemicals they use to the public, this is only voluntary. **<u>Recommendations</u>** - **Four recommendations**: 1. S.50(4B) of the *IA 2015* should be amended to remove the volumes of fluid required for an operation to constitute UHF. It should account for any operation that includes forcing cracks in impermeable strata in order to release hydrocarbons (such as oil and gas from shale). This is because there have been improvements in dry hydraulic fracturing in the United States (see section 2.3.4.) which, if applied to the UK, would significantly reduce the quantity of fluid needed to

conduct UHF (meaning that such processes may fall outside the volumes cited in this section of the *IA 2015*). As long as the primary motivation remains the same, the activity should be subject to the same legislative and regulatory controls that are required for UHF with significant volumes of fluid.

2. The EA (along with the HSE) must be stringent and inflexible with the term non-hazardous and must always consider the integrity of the well before granting a permit to use chemicals.
3. Whilst s.50 of the *IA 2015* clearly states that substances used in UHF are subject to approval from the environmental regulator, s.44(1) of the *IA 2015* should be amended to prohibit any substance being used in the future. The government should consult with relevant organisations (from industry, professional bodies, and academia) in order to provide a short, definitive list of appropriate chemicals to be used in UHF in the UK. Such a list should only contain chemicals that the EA have traditionally considered to be non-hazardous.
4. Operators should not be able to hide behind commercial confidentiality and should be required to openly disclose, to the public, what chemicals are being used at each fracking site. The *IA 2015* should be amended to incorporate public disclosure of chemicals in the best interests of environmental protection and public health.

Well Integrity

<u>Current Controls</u>

- S.50(4A) of the *IA 2015* requires the HSE to visit wells, as well as to receive relevant information and notifications from an independent well examiner. This is in-line with Borehole Sites and Operations Regulations (1995) and Offshore Installations and Wells (Design and Construction) Regulations (1996) (RSRAE, 2012). Whilst these regulations do not necessarily require MBS's, this is standard practice for wells in order to protect well integrity. As the RSRAE (2012: 27) denote, wells: 'should be designed and constructed so that as far as is reasonably practicable, there can be no unplanned escape of fluids from the well; and risks to the health and safety of persons... are as low as is reasonably practicable.'
- There is no legislation or regulation for the long-term management of wells post-abandonment. Whilst operators must keep well examination reports for

a minimum of six months after a well has been abandoned (RSRAE, 2012), there is no legal or financial requirement for an operator to manage a well after it has been abandoned. **<u>Recommendations</u>** - MBS's are the best-known way to prevent substances escaping the well in the short-term and should be used in all fracking wells. - The constituents of well casing (such as concrete and steel) can rust, crack, shrink (RSRAE, 2012: 25-26), and deteriorate over time (Davies et al. 2014). This means that well integrity may be compromised in the long-term leading to contamination of the environment from the substances that are inevitably left within a well (although this will vary, it will always include traces of chemicals used in fracking processes, alongside geological matter existing within deep-level land). As a result, this situation should enable the government to move towards a prohibition of fracking in the interests of public health, safety, and environmental protection according to the precautionary principle of environmental law. This principle requires 'states to take action' where there is a risk (or evidential uncertainty of a risk) to human health or the environment (Wolf and Stanley, 2014: 16). Studies such as those from Davies et al. (2014) demonstrating that there is a lack of monitoring of onshore wells (and even a grave lack of knowledge as to the ownership of up to 53% of UK wells) clearly demonstrates a great deal of long-term risk.
Flaring **<u>Current Controls</u>** - S.50(4A) of the *IA 2015* requires the EA to distribute environmental permits to operators requiring compliance with a Waste Management Plan that considers monitoring of emissions of methane into the atmosphere. - Operators will use flaring (as do many other industrial processes) in the early stages of fracking in order to dispose of unusable dirty gas. **<u>Recommendations</u>** - **No recommendations**. Flaring is an unavoidable by-product of UHF. However, the government must consider the environmental implications of allowing industrial practices that require flaring in order to meet conditions set out in the *Climate Change Act 2008* that requires the UK carbon account to be 80% lower in 2015 than 1990 baseline levels.

Table Thirteen: *Recommendations*.

8.3. **Solutions**

UHF is not the only way to produce consumable energy for the UK market. There are other means of accessing energy such as importing fossil fuel resources from other nations. The problem with this, however, is that importing natural gas (for example) is a costly endeavour. It is much cheaper (in terms of the balance of payments) for a state to produce their own gas. Furthermore, it is profitable to sell domestically produced gas, which is consistent with making a profit underlined by ToP theory. However, the fact remains that, in the long-term, not conducting UHF does not result in a shortage of natural gas which is available from several different places. As PN16 (an oil and gas professional) denoted:

PN16: "*the UK has probably one of the most diverse energy supply mixes you can think of, even if you just looked at methane. A large portion of our gas comes from Norway via the (difficult to hear) which is coming in in Easington near Hull, close by. We have an interconnector with Holland, er, as well. Er, LNG, liquefied natural gas is in plentiful supply, er, from both the middle east, um, far east you wouldn't track that much. So, there's the middle east, west of Africa, um, and even the Caribbean, um, Trinidad is producing quite large volumes. Um, plus the US which has started exporting liquefied natural gas as well. So, there are plenty of sources for us to draw on when it comes to getting hold of natural gas.*"

Therefore, it may be possible to consume energy in other ways, which leads to the second solution concerning renewable forms of energy.

The thesis has highlighted several different areas that may create environmental harm in the UK as a result of fracking processes. However, there are numerous different options for producing consumable energy in ways which create much less environmental harm per unit of energy created. The many forms of renewable energy, for example, present the government and (traditionally) fossil fuel corporations, with energy supplies that will inevitably outlive the non-renewable nature of oil and natural gas that is formed by geological processes over millions of years (POST, 2011: 2). The continuity of renewable energy should be more attractive to treadmill actors where investment could result in long-term profit-making, rather than the short-term returns on investment provided by extreme energy technologies. Whilst the production of energy from renewable resources would ultimately reach a point where production can no longer increase (i.e. there is enough energy for a stable human population), the continuity of renewable energy would enable a steady treadmill that continues running indefinitely, rather than an accelerating treadmill that is inevitable by extracting fossil fuels.

Investment in renewable technology could be a particularly advantageous strategy for the UK (as opposed to investment in UHF). The UK has access to some forms of renewable energy that other countries do not have access to. For example, being a country separated from mainland Europe, the UK has a long and varied coastline that could accommodate offshore wind and wave and tidal technologies. Land-locked countries do not have access to such forms of energy. Although it is recognised that renewable technologies are not perfectly efficient (Baldwin, no date; McCluney, 2004: 5) and are not totally devoid of creating environmental harm (Faulkner, 2014: 22-27; Pelc and Fujita, 2002: 475-476), Figure Three (below) shows that the amount of energy used in producing renewable energy is significantly less than that needed to produced non-renewable energies:

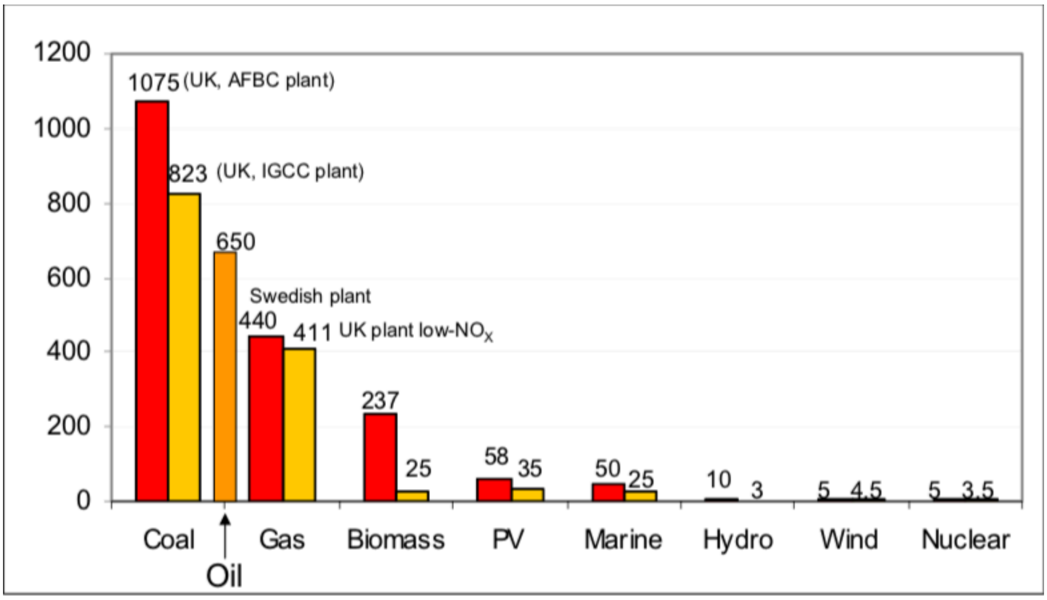

Figure Three: *Carbon Footprint of Electricity Generation Technologies*. Baldwin (no date: 7).

Therefore, from an eco-philosophical perspective, decision-making focussed on renewable energies clearly represents a much more ecocentric approach to energy production (where human and ecological values are more harmonious than the dominance of human values that constitute anthropocentrism).

A penultimate solution to preventing the environmental harms associated with extreme energy extraction techniques would be to provide nature with legal rights. This could take the form of human rights[35] (see: Turner, 2014: 17-22), a new global constitutionalist world order providing 'a less-pronounced role of the state' (Kotzé, 2012: 224), or a 'great jurisprudence' whereby (proposed) human-made laws that infringe or violate the fundamental rights of the environment are deemed to be 'unlawful' (Cullinan, 2011: 13). The problem with such legal transformations, however, is that states would be required to implement legal changes (either individually or collectively) which ultimately contradicts the neo-liberal agenda of achieving continuous economic growth. Under ToP theory, incessant

[35] Such as the rights to: life, health, water, housing or shelter, and property (Turner, 2014: 17-22).

environmental degradation is required to facilitate such continuous economic growth (Stretesky et al. 2014: 101), and natural rights would only serve to prohibit such growth rather than to foster it.

A final way to overcome the problems associated with the ToP (and therefore UHF) would be for society to somehow disengage with capitalism which is the driving force that necessitates accelerated production (Lueck, 2007: 254-257). Whilst it is rather incomprehensible to conceive how such a system could be overthrown in contemporary western society (Lueck, 2007: 254-255), it is not guaranteed that a different economic system (such as socialism) would not still choose to utilise natural gas resources as a form of energy creation. Therefore, the way in which decision-makers decide how energy is created (such as the perspectives given through eco-philosophy) are essential in the ability of society to move away from fossil fuels to more renewable (and less carbon-intensive) technologies. However, embedding a more ecocentric approach to law-making where energy creation is concerned is prohibited by the state-corporate relationships that facilitate natural gas extraction as a result of the treadmill of production.

8.4. <u>**Contribution to Academic Research and Directions for Future Investigation**</u>

Green criminology has so far failed to directly engage with the process of UHF. There are only a few scholars who have specifically integrated green criminology with fracking globally (Cardenas and Vega, 2016; Opsal and Shelly, 2014; Stretesky et al. 2014: 61-63) and even fewer who have done so in a UK context (Lampkin, 2016; In Press; Short and Szolucha, In Press; Stretesky et al. 2018a).

Green criminology is integral to the understanding of UHF due to the legal nature of the practice in many countries. By definition, orthodox criminology cannot adequately analyse the environmental harms associated with fracking due to its legality. Therefore, green criminology is the only discipline that can discuss harms associated with UHF prior to full scale development in the UK. Environmental disciplines and quantitative techniques can only engage in research after harms have already occurred.

To the best knowledge of the researcher at the time of submission, this thesis is the first piece of academic research to interview a range of key-informants from different backgrounds in order to obtain a diverse view of the potential for UHF in the UK to create environmental harm. Furthermore, the confidential nature of the research methodology would make it an impossible study to directly replicate (in terms of interviewing the same participants, although the same methodological approach could be imitated). Interviewing a diverse range of key-informants with different skills, backgrounds and knowledge of UHF in the UK has been useful in terms of identifying different areas for environmental harm to occur. It is unlikely that such a diversity would have been achieved by interviewing one particular type of participant (i.e. anti-fracking campaigners, or oil and gas professionals) because of the unique background of each person who had often acquired specialised knowledge (i.e. geologist, regulator, or water consultant). Additionally, this methodology has enabled a level of objectivity in the sense that a breadth of views of UHF issues in the UK were discussed as opposed to focussed (and possibly subjective) discussions which may occur from interviewing one type of participant. The selective sampling techniques employed enabled the researcher to select which participants were the most likely to obtain such a breadth of debate.

This is not, however, the first academic research to use interviews to better understand fracking in a UK context. Szolucha (2016) collected primary data in the form of 'anthropological fieldwork, including interviews and observations' in order to better understand the social impacts of shale gas projects in Lancashire. Similarly, Short and Szolucha (In Press: 3) adopt a mixed-methods approach (involving a collection of ethnographic research and participatory research, participant observation, collated fieldnotes, semi-structured interviews and textual analysis of planning application documents) in order to analyse the concept of *collective trauma* from a green criminological perspective. As a result, 28 interviews were undertaken with local residents in Lancashire. These interviews unveiled key objections to fracking in Lancashire which interestingly are all environmental harms as opposed to solely social harms. As Short and Szolucha (In Press: 3) suggest these technical objections included:

> '(1) large quantities of truck traffic required to frack wells; (2) industrialisation of the landscape; (3) likelihood of water pollution if fracking were to go ahead; (4) air quality and localised pollution; (5) site noise, seismicity and the likelihood of localised earthquakes.'

Whilst this thesis shares some similar results with Short and Szolucha's (In Press) work, interview findings represent the views of local residents as opposed to the diversity of views ascertained by interviewing key-informants.

Finally, there has been some academic research conducted into public perceptions of shale gas development in the UK using online surveys (Whitmarsh et al. 2015) and focus groups (Williams et al. 2017), and interviews have been conducted with anti-fracking campaigners on the policing of peaceful protest (Gilmore et al 2014). However, none of this research deals specifically with environmental harm.

The reason for a lack of research into the environmental harms of UHF in the UK is probably due to the process currently being situated at the exploratory phase, as opposed to a production phase (see Appendix One). However, this thesis has identified several areas in which environmental harm may occur. I suggest that the prevention of initial environmental harm is only obtainable through such qualitative research techniques. After all, considering research on the likelihood of environmental harm prior to harm occurring is an obvious way to impact public policy in a manner which may prevent harm, mirroring the precautionary principle of environmental law (Wolf and Stanley, 2014: 16). Quantitative research methodologies that measure environmental harm that has already occurred, fails to prevent the harm from occurring in the first place.

However, this is not to suggest that quantitative research is not important. On the contrary, quantitative methodologies (such as, for example, testing methane concentrations in groundwaters in close proximity to fracking sites before and after UHF) are exceptionally important in shaping public policy through the identification of environment degradation. Furthermore, this is even more quintessential if state-corporate relationships ensure the development of UHF in the UK, even in spite of qualitative research (such as this thesis) that may identify environmental harm. As a result, identifying potential areas for environmental harm to occur prior to the development of UHF, such as conducting human rights impact assessments (Short et al. 2015) or social impact assessments (Short and Szolucha, In Press) can be seen as equally important as the quantitative research that identifies environmental harm that has already occurred.

It appears that time is running out in terms of conducting qualitative research prior to the commencement of fracking in the UK and, as a result, it is unlikely that public policy on fracking will be sufficiently informed by the results of such research. In April 2018, Cuadrilla announced that they had successfully completed the UK's first shale gas well, with plans to stimulate the well by the end of the year (Cuadrilla Resources, 2018). Therefore, future research needs to focus on the key areas where environmental harm may occur, which have been identified in this thesis (see Table Twelve).

In the longer-term, further research needs to consider how to better protect the natural environment from production processes that cause environmental harm. Giving nature legal rights, for example, could act as a mechanism to prevent natural gas extraction (or other processes that contribute to environmental harm) from occurring. Therefore, legal rights of nature could prevent environmental harm occurring in the first place (rather than attempting to regulate harm that is legally permitted), which more closely mirrors the precautionary principle of environmental law. The possibility of attributing such rights to geological formations (such as shale) is something that has not yet been considered, but could be used to prevent the environmental harms associated with shale gas production.

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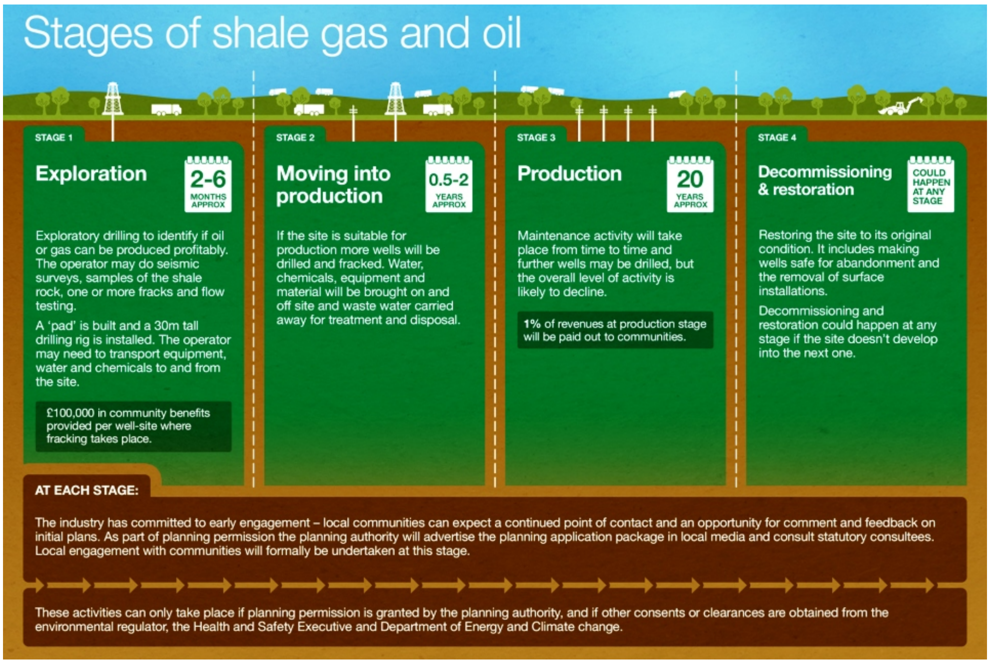
Appendices

Appendix One:

Department for Business Energy and Industrial Strategy (2017a) *Guidance on Fracking: Developing Shale Gas in the UK.* [Online]. Available at: https://www.gov.uk/government/publications/about-shale-gas-and-hydraulic-fracturing-fracking/developing-shale-oil-and-gas-in-the-uk (Accessed: 23rd February, 2018).



Appendix Two:

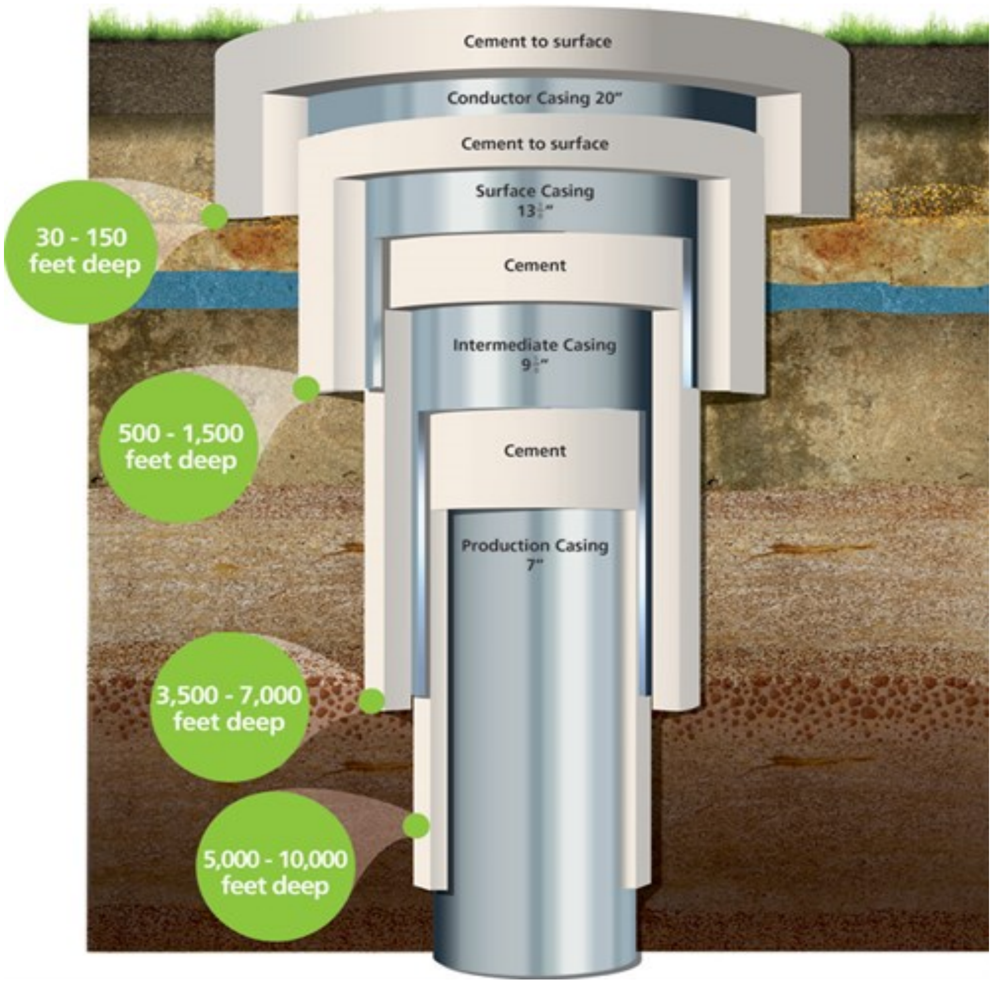
Halliburton (2016) *Pennsylvania: What's in the Fluids? WaterFrac Formulation*. [Online]. Available at: http://www.halliburton.com/public/projects/pubsdata/Hydraulic_Fracturing/fluids_disclosure.html (Accessed: 15th February, 2016).

Constituent Name	Generic Name	CAS Number	Common Use	Hazardous as Appears on MSDS
Acetic Anhydride	Organic Acid	108-24-7	Agricultural Microbiocide Agent	Yes
Acetic Acid	Organic Acid	64-19-7	Processed Fruit, Cheese, Meat and Poultry	Yes
Acetophenone, Thiourea, Formaldehyde Polymer	Modified Thiourea Polymer	68527-49-1	Industrial Acid Corrosion Inhibitor for Cooling Towers and Boilers	No
Alcohol C12-C16 Ethoxylated	Alcohols, Ethoxylated	68551-12-2	Car Wash Liquid, Laundry Stain Remover, Air Freshener	No
Alcohol, C14-C15 Ethoxylate	Polyoxyalkylene	68951-67-7	Liquid Detergent, Disinfectant Toilet Cleaner, Stain Remover	No
Alpha Olefin Blend	Olefins	64743-02-8	Industrial / Commercial Metal Cutting Agent	No
Ammonium Chloride	Inorganic Salt	12125-02-9	Hand Wash, Shampoo, Breakfast Cereal	No
Crystalline Silica, Quartz	Silica	14808-60-7	Hand Cleaner, Laundry Cleaner, Cat Litter	Yes
Fatty Acid Tall Oil Blend	Fatty Acids, Tall Oil	61790-12-3	Car Polish, Industrial Hand Cleaner	No
Formaldehyde	Aldehyde	50-00-0	Liquid Detergent, School Glue, Hand Soap	No
Hydrochloric Acid	Inorganic Acid	7647-01-0	Table Olives, Unripened Cheese, Cottage Cheese	Yes
Hydrotreated Light Petroleum Distillate	Hydrocarbon - Petroleu	64742-47-8	Oil Wood Stain, Air Freshener, Surface Cleaner Aerosol	Yes

	m Distillate			
Methanol	Alcohol	67-56-1	Furniture Refinisher, Liquid Hand Soap, Windshield Washer Concentrate, Hops Extract	Yes
Phosphonic Acid, [[(phosphonomethyl)imino]bis[2,1-ethanediylnitrilobis(methylene)]] tetrakis-, Ammonium Salt	Organic Phosphonate	70714-66-8	Biocide in Industrial Water Treatment applications**, Industrial and Institutional Cleaning, Pulp and Paper Industry	No
Polyacrylamide Copolymer	Polyacrylamide Copolymer	*	Testing for Use as Drug Delivery and in Textile Dye Removal**	No
Propargyl Alcohol	Alcohol	107-19-7	Cement and Grout Cleaner, Industrial / Commercial Metal Cleaner	Yes
Sodium Chloride	Inorganic Salt	7647-14-5	Macaroni and Noodle Products, Canned Corn, Tomato Concentrate, Frozen Peas	No
Sorbitan Monooleate	Fatty Acid Ester	1338-43-8	Vitamin A Supplements, Sun Block Towels	No
Sorbitan Monooleate Ethoxylated	Fatty Acid Ester Ethoxylate	9005-65-6	Shortening, Ice Cream, Chocolate and Chocolate Products	No
Tall Oil Acid Diethanolamide	Fatty Acid Tall Oil Amide	68155-20-4	Liquid Wax, Antiseptic Hand and Body Wash	No
Tributyltetradecylphosphonium Chloride	Organic Phosphonium Salt	81741-28-8	Industrial Water Treatment Agent	Yes
Water	Water	7732-18-5	Water Present in Additives (Not Water used as Carrier Fluid)	No

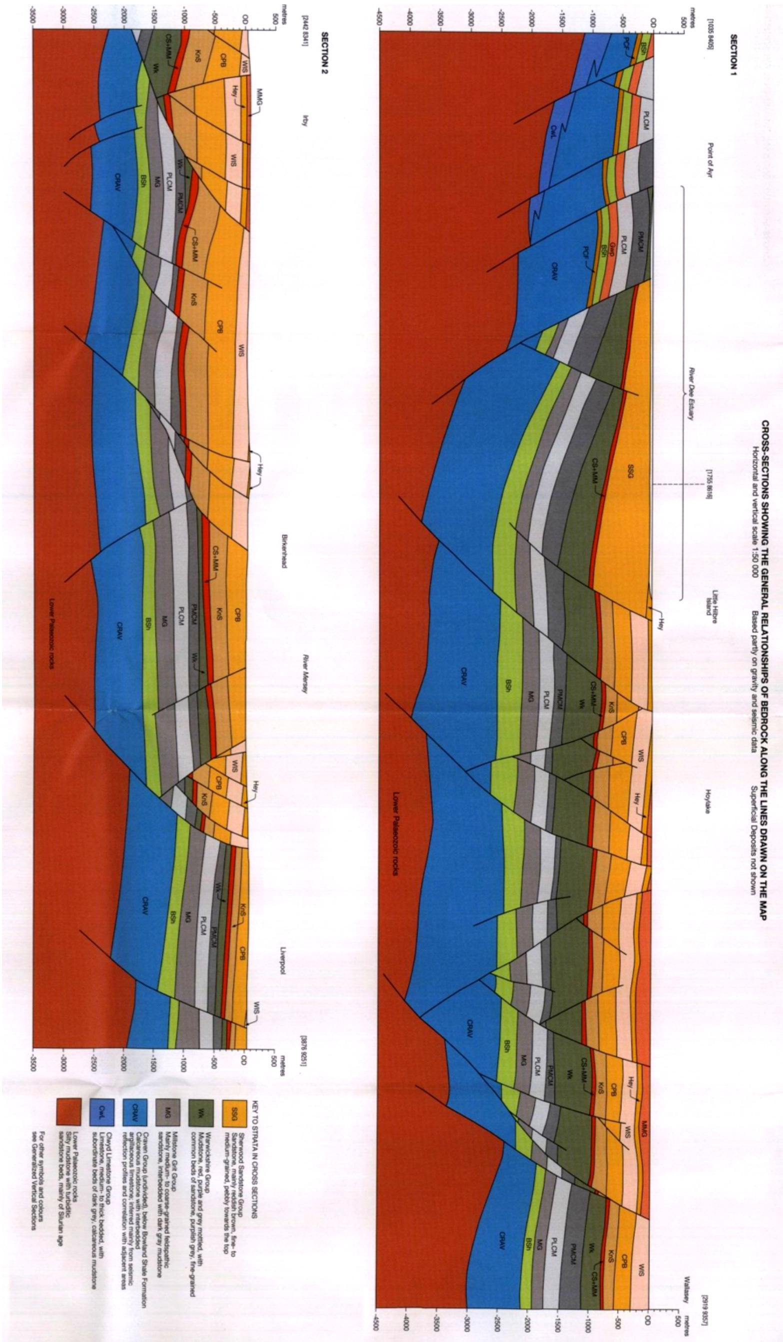
Appendix Three:

IGAS (2017a) *Well Integrity: How we Construct the Well*. [Online]. Available at: http://www.igasplc.com/what-we-do/extracting-gas-responsibly/well-integrity (Accessed: 09th February, 2016).



Appendix Four:

Advanced Resources International (2013) *EIA/ARI World Shale Gas and Shale Oil Resource Assessment Technically Recoverable Shale Gas and Shale Oil Resources: An Assessment of 137 Shale Formations in 41 Countries Outside the United States.* Prepared for: U.S. Energy Information Administration and U.S. Department of Energy. [Online]. Available at: http://www.adv-res.com/pdf/A_EIA_ARI_2013%20World%20Shale%20Gas%20and%20Shale%20Oil%20Resource%20Assessment.pdf (Accessed: 08th February, 2016).



Appendix Five:

Third Energy Email Response to Interview Request.

Dear Mr Lampkin

We are responding to your request for an interview
with Third Energy as part of your PhD research. We like to support students and research projects whenever possible. With that principle in mind, we have considered your request but have some points we would like you to clarify about the research and your methodology prior to arranging an interview. We take research done in UK universities seriously and would like to understand the basis of your research so we are able to provide the best assistance.

First, there is some dissonance between the aim of the PhD as stated in your email requesting Third Energy participation; the Project Title given in your Participant Information Sheet; and the aims set out in the Participant Information Sheet. Please could you clarify the aims of this research project and how they align with the Project Title.

Secondly, the Project Title states that this will be an "Empirical Investigation into the Technique of Onshore Hydraulic Fracturing in the United Kingdom". This is also less than clear. If it is a truly empirical study, would we be correct in the assumption that an applicable and sufficient data set will be utilised e.g. data from the 200 conventional onshore wells that have been hydraulically fractured in the UK? Alternatively, if you are referring to the use of high pressure, high volume hydraulic fracturing in the context of unconventional gas resources your evidence will be restricted as there is not yet an available UK data to draw upon for empirical study.

However, you may be considering the use of datasets from outside the United Kingdom. As you will know, the United Kingdom has a significantly different regulatory regime from both the United States and Australia, so it would be erroneous to extrapolate data from those countries to future operations in the United Kingdom. Indeed Public Health England in their 2014 report stated *'Caution is required when extrapolating experiences in other countries to the UK since the mode of operation, underlying geology and regulatory environment are likely to be different'.* The 2012 joint Royal Society and Royal Academy of Engineering Report *"Shale gas extraction in the UK: a review of hydraulic fracturing"* also highlighted the differences between the United States and the United Kingdom.

We would be pleased to learn which data you intend to draw upon and the proposed methodology for arriving at a balanced view of the chosen data set. If your research is relying upon experiences from other countries, you must be able to set out where you concur with the conclusion of professionals from Public Health England, the Royal Society and Royal Academy of Engineering so have not used that data and, equally, where you believe they were not correct and have therefore been able to utilise those datasets.

Fourthly, there is an in-built assumption in the Project Title that onshore hydraulic fracturing in the United Kingdom will cause "Environmental and Social Harm" and that there will be "Victims". This is a strange starting place for a piece of research. Please could you explain your justification for this pre-defined thesis with respect to events yet to happen – assuming you are considering the high pressure, high volume hydraulic fracturing of unconventional gas resources - and why this is a rational starting point for advanced research which should, by definition, be objective and not start with a pre-defined conclusion.

In advance of interview, it would be of value to fully assess the current legislative and regulatory framework and protections in place in order to establish your projections of how you think they could fail and which specific environmental and social harms could then result. For clarification, please could you explain the parameters you will be using to evaluate Social Harm and comparators, if any, from other industries?

Finally, to make the most of an interview, we would need confirmation that you are fully familiar with the detail of our applications for planning permission and the requisite environmental permits for the hydraulic fracturing of the KM8 well at Kirby Misperton. This will ensure that both Third Energy's and your time would be spent effectively and not in seeking information that is already in the public domain (we find the lack of robust desk research prior to interview can be an issue). The Environmental Statement includes many of the subjects you may want to cover.

We look forward to your response. If the interview goes ahead, we would like to suggest that you travel to North Yorkshire so that you could also visit one of our sites so as to have first-hand experience of onshore natural gas operations.

Appendix Six:

Table Five: Explanation of the Research Task.

Task	Explanation
Literature Review	I conducted a detailed review of the literature considering UHF in the UK and globally. This unearthed several economic and environmental concerns for UHF in the UK. Additionally, I conducted a literature review of academic work into three theoretical approaches that were used to understand UHF and to incorporate into the analysis and conclusions of the data. These approaches were: green criminology, ToP theory, and eco-philosophy.
Formulating Research Design	This stage involved investigation into different research methodologies. Ultimately, qualitative data was determined as the most appropriate form of data collection to consider the complexities of UHF identified through the literature review. More specifically, purposive and snowball sampling were selected, as well as a mixed-methods approach combining face-to-face and telephone interviewing techniques to collect data. Consideration was given to ethics and the research proposal passed through the University of Lincoln's ethics committee.
Formulation of Approach list	I conducted desk-based research to identify suitable prospective interviewees. I generated an approach list largely through public domain information.
Approaching Prospective Participants and	I used telephone numbers and email addresses accessed on the public domain to approach participants. I sent Participant Consent Forms

arranging interviews	and Participant Information Sheets at this stage (see ethical considerations at section 4.5.).
Conducting Interviews	I conducted face-to-face and telephone interviews at a time and place arranged with (and most suitable for) each participant.
Transcribing Interviews	I transcribed all 20 interviews.
Coding Interviews	I coded all 20 interviews which involved assigning 'tags' to various 'chunks' of data. The aim of this was to dissect the data making it easier to analyse.
Formulating Results	I went through each deductive code in turn to formulate results.
Analysing Results	After formulating results and dividing responses in similar categories, I incorporated elements of academic literature on different topics to explain and validate the meaning of what participants said.
Reconfiguration of Literature Review	Reconfiguration of the literature review based on new research that had been published since the original literature review.
Drawing Conclusions	I used the conclusions of each section of the results and analysis to draw conclusions with regards to each deductive category.

Table Five: *Explanation of Each Research Task*.

Appendix Six:

List of Pre-Determined Interview Questions.

Introductory Question: Could you explain how and why you think fracking has come about in the UK? Perhaps starting with your knowledge of how fracking generally started in a global sense and then how it came to be developed in the UK from there.

Question One: What impact, positive or negative, do you believe fracking will have on jobs in the UK?

Question Two: What impact, positive or negative, do you believe fracking will have on the property value of those people who live in communities that host fracking?

Question Three: What impact, positive or negative, do you believe fracking will have on the UK's energy security?

Question Four: What impact, positive or negative, do you believe fracking will have on the economy of the UK?

Question Five: Section 45 of Part 6 (Payment Scheme) requires relevant energy undertakings to make payments to communities for the benefit of areas in which relevant land is situated. The government has stated that these benefits will be £100,000 per hydraulically fractured well site at exploratory stage and 1% of revenue at production stage. Additionally, the industry has confirmed that operators will contribute a voluntary one-off payment of £20,000 for each lateral well that extends by more than 200M. Do you believe that these financial incentives (CFI's) are the worth communities agreeing to fracking?

Question Six: There is conflicting research on the extent to which fracking may or may not affect water aquifer's. What, if any, impact do you believe fracking has on water aquifers?

Question Seven: What impact, if any, do you believe fracking has on 'seismicity' or 'earthquakes'?

Question Eight: In the United States, hazardous chemicals have been used in fracking processes. Currently in the UK, the Environment Agency is responsible for regulating the chemicals used in fracking via the use of a permit system identified in Section 50 of Part 6 (Onshore Hydraulic Fracturing: Safeguards) in the Infrastructure Act 2015 which condones the use only on non-hazardous chemicals. Although chemicals used are likely to vary from company to company and from location to location, could you explain your knowledge with regards to what substances are expected to be used in hydraulic fracturing fluids?

Question Nine: There is conflicting research on the extent to which fracking wells may or may not leak during production of fracking wells and after the de-commissioning of fracking wells. Can you explain your knowledge of well integrity related to fracking?

Question Ten: The fracking production process is likely to use large quantities of water. What impact, if any, do you believe fracking will have on the UK's water resources?

Question Eleven: There is conflicting research on the amounts of water that return to the surface during and after fracking operations. However, there is an agreement that much water does return to the surface at some point. With this in mind, how do you believe this wastewater will be disposed of in the UK?

Question Twelve: In the United States, excess gases have been disposed of through flaring such gas into the atmosphere. Firstly, do you believe this method will be used in the UK and secondly, what impact, if any, do you believe flaring will have on the environment?

Appendix Seven:

<u>Participant Consent Form</u>

Title of Research Project: The Potential Impact of Environmental and Social Harm on Victims: Interviews with Key-Informants to the Unconventional Hydraulic Fracturing Industry in the United Kingdom.

Name of Lead Researcher: **Jack Lampkin** (University of Lincoln).

Participant Identification Number for this project:

Please initial box

1. I confirm that I have read and understand the information sheet
   dated ....explaining the above research project
   and I have had the opportunity to ask questions about the project.

2. I understand that my participation is voluntary and that I am free to withdraw
   at any time without giving any reason and without there being any negative
   consequences. In addition, should I not wish to answer any particular
   question or questions, I am free to decline.

3. I understand that my responses will be kept strictly confidential.
   I give permission for members of the research team to have access to my
   anonymised responses. I understand that my name will not be linked with
   the research materials, and I will not be identified or

identifiable in the
report or reports that result from the research.

4. I agree for the data collected from me to be used in future research.

5. I agree to take part in the above research project.

Name of Participant Date Signature

Lead Researcher Date Signature

To be signed and dated in presence of the participant

Copies:

Once this has been signed by all parties the participant should receive a copy of the signed and dated participant consent form, the letter/pre-written script/information sheet and any other written information provided to the participants. A copy of the signed and dated consent form should be placed in the project's main record (e.g. a site file), which must be kept in a secure location.

Appendix Eight:

<u>Participant Information Sheet</u>

Lead Researcher: Mr. Jack Lampkin (University of Lincoln);
Supervisor: Prof. Matthew Hall (University of Lincoln).

Project Title: The Potential Impact of Environmental and Social Harm on Victims: Interviews with Key-Informants to the Unconventional Hydraulic Fracturing Industry in the United Kingdom.

Dear Participant,

You are being invited to take part in a research project carried out by Jack Lampkin of the University of Lincoln. Before you decide to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to decide whether or not you wish to take part.

The aims of the project are:

- What do key informants understand to be the most salient concerns regarding the potential for human victimization in the UK?
- What do key informants understand to be the most salient concerns regarding the potential for environmental victimization in the UK?
- What do key informants understand to be the economic implications of unconventional hydraulic fracturing in the UK?

To these ends you are being invited to take part in a face-to-face interview.

It is important that you do not speak of anything in your responses which could identify yourself personally. If this

happens by mistake, the researcher and participant will discuss this at the end of the interview and the researcher will delete any names/phrases which may identify you personally. If the researcher comes across any names/phrases which could identify you personally whilst transcribing the interview for the purposes of the research, the researcher will delete any such names or phrases.

It is up to you to decide whether or not to take part. If you do decide to take part, you will be given this information sheet to keep (and be asked to sign a participant consent form) and you can still withdraw at any time. You are, of course, free to decline to answer any questions asked of you, at any time, without reason.

If you would like any more information, or for any reason you have a complaint regarding your participation in the research, you can contact the Lead Researcher (Jack Lampkin) or the Supervisor of the Lead Researcher (Matthew Hall) at:

Jack Lampkin	*Prof. Matthew Hall*
University of Lincoln Law School	*University of Lincoln Law School*
Brayford Pool	*Brayford Pool*
Lincoln	*Lincoln*
LN6 7TS	*LN6 7TS*
E-mail: 14575757@students.lincoln.ac.uk	*E-mail:* mhall@lincoln.ac.uk

Should you feel your complaint has not yet been handled to your satisfaction you can contact the University of Lincoln's Registrar:

Registrar's Office
University of Lincoln
Brayford Pool
Lincoln, LN6 7TS

All the information that we collect about you during the course of the research will be kept strictly confidential. You will not be able to be identified in any reports or publications.

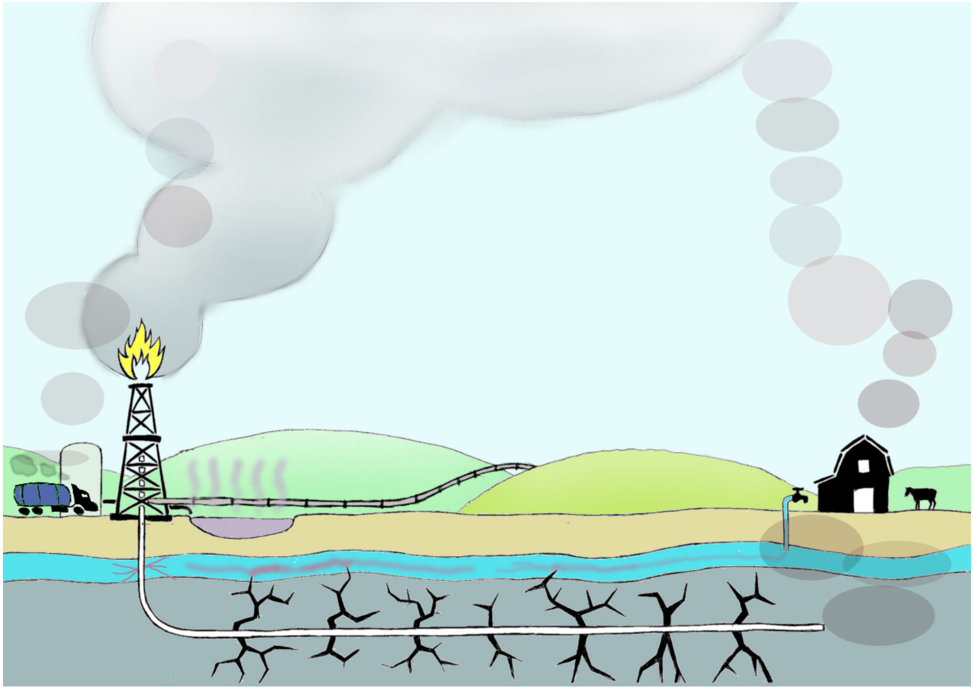
The results of the research are likely to be published in 2018/2019, you will be able to obtain a copy of publication from Jack Lampkin or Matthew Hall.

This project has been ethically approved via the University of Lincoln Law School ethics review procedure, in line with national standards.

Thank you for taking part in the project!

Appendix Nine:

Fracking Free Ireland (no date) *Ireland – Keep Ireland Fracking Free – Don't Frack Gods Creation*. [Online]. Available at: http://www.frackingfreeireland.org (Accessed: 02nd July, 2016).

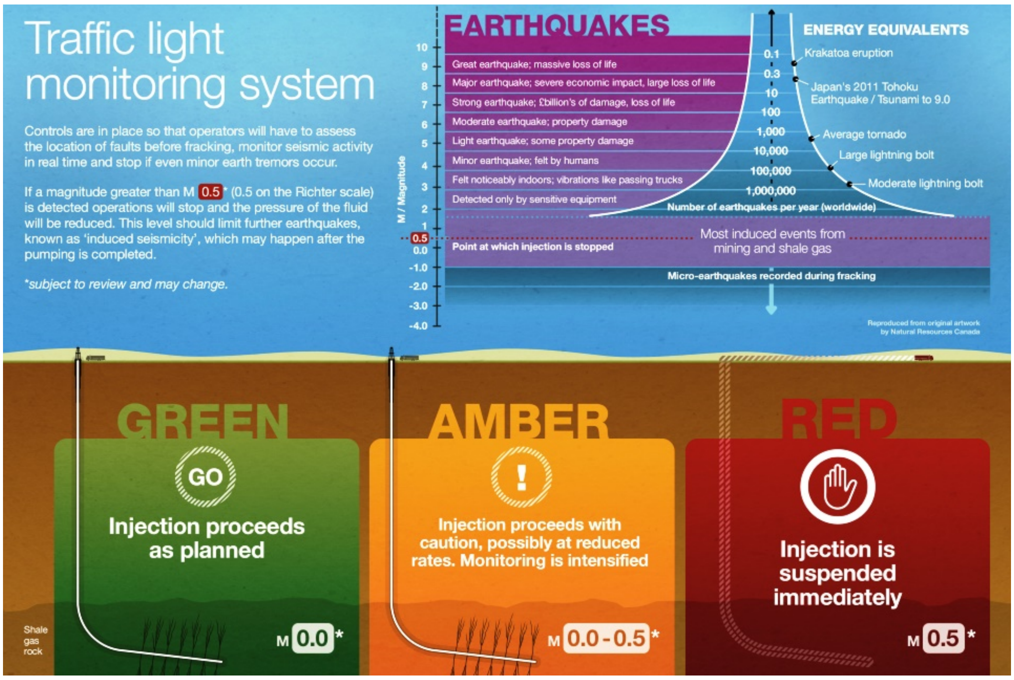


Appendix Ten:

Frack Free Bolsover (2017) *Home*. [Online]. Available at: http://www.frackfreebolsover.org.uk (Accessed: 30th August, 2017).

Appendix Eleven:

Department for Business Energy and Industrial Strategy (2017a) *Guidance on Fracking: Developing Shale Gas in the UK*. [Online]. Available at: https://www.gov.uk/government/publications/about-shale-gas-and-hydraulic-fracturing-fracking/developing-shale-oil-and-gas-in-the-uk (Accessed: 28th September, 2017).



Appendix Twelve:

Stuart, M.E. (2014) Hydrogeological Aspects of Shale Gas Extraction in the UK. Produced for: Natural Environment Research Council. [Online]. Available at: http://nora.nerc.ac.uk/507404/1/UGas%20presentation%20v2.pdf (Accessed: 21st September, 2017).

Constituent	Composition (% by vol)	Example	Purpose
Water and sand	99.50	Sand suspension	"Proppant" sand grains hold microfractures open
Acid	0.123	**Hydrochloric acid**	Dissolves minerals and initiates cracks in the rock
Friction reducer	0.088	**Polyacrylamide*** or mineral oil	Minimizes friction between the fluid and the pipe
Surfactant	0.085	Isopropanol	Increases the viscosity of the fracture fluid
Salt	0.060	Potassium chloride	Creates a brine carrier fluid
Gelling agent	0.056	Guar gum or hydroxyethyl cellulose	Thickens water to suspend the sand
Scale inhibitor	0.043	Ethylene glycol	Prevents scale deposits in pipes
pH-adjusting agent	0.011	Sodium or potassium carbonate	Maintains effectiveness of chemical additives
Breaker	0.01	Ammonium persulphate	Allows a delayed breakdown of gel polymer chains
Crosslinker	0.007	Borate salts	Maintains fluid viscosity as temperature increases
Iron control	0.004	Citric acid	Prevents precipitation of metal oxides
Corrosion inhibitor	0.002	n,n-dimethyl formamide	Prevents pipe corrosion
Biocide	0.001	**Glutaraldehyde***	Minimizes growth of bacteria that produce corrosive and toxic by-products
Oxygen scavenger	-	Ammonium bisulphite	Removes oxygen from the water to prevent corrosion